EAPSpeaks

Earth, Atmospheric and Planetary Sciences Massachusetts Institute of Technology

Reconstructing the History of El Niño from Galapagos Lakes

Julian Sachs and Rienk Smittenberg

The largest perturbation to global climate on an interannual time scale is the El Niño-Southern Oscillation (ENSO). Surface water temperatures (SST) rise in the Eastern Equatorial Pacific (EEP) when the upwelling of cool, nutrient-rich water diminishes. Fish stocks plummet and birds and mammals perish, causing widespread ecologic and economic disruptions. Global precipitation patterns are altered, causing drought in normally wet locations and torrential rains in desert regions. Will El

Figure 1 Research team members (left to right), Paul Colinvaux, Miriam Steinitz-Kannan, Julian Sachs, Rienk Smittenberg (kneeling), Mike Miller. Please see Box 1 for information about each participant.

Niños become more intense and/or frequent in response to global warming? Presently we do not know. Predictions range from a significant strengthening of El Niño and/or an increase in its frequency (Collins, 2000a; Timmermann et al., 1999), to no effect or even weakening (Collins, 2000b; Fedorov & Philander, 2000). Paleoclimatic data required to evaluate these models are scarce and contradict each other.

Recent SST and salinity estimates in the eastern equatorial Pacific (EEP) and western Equatorial Pacific (WEP) conclude that El Niños were more intense under glacial relative to Holocene conditions. This conclusion is diametrically opposed to that reached in an analysis of Papua New Guinea-coral $^{18}O/^{16}O$-records which indicate intensified and/or more frequent El Niños under interglacial conditions. Focusing on Holocene variability of ENSO provides a similarly contradictory set of conclusions.

Straddling 0° latitude in the cold tongue of the EEP, the Galapagos are ideally positioned to record variations in ENSO through time. Lakes on the islands serve as fixed sampling stations of the eastern Pacific marine climate. Aridity of the Galapagos is caused by the atmospheric inversion that results from upwelling of cold water. This prevents the establishment of convection cells that should otherwise bring rain to a tropical oceanic island. Only in the December to February period, when the "meteorological equator" moves to its most southerly position, does the inversion collapse, bringing rain. In some years, however, the encroachment of surface water from the west thickens the surface layer and removes deeper cold water from the upwelling system, SSTs rise, intensifying tropical convection cells. The prolonged torrential rains that result from this, the meteorologist's El Niño, leave clear proxy records in sediments.

Comparison of the records of inferred water level variations in El Junco Lake on the Galapagos island of San Cristobal, reconstructed flood deposits in Laguna Pallacocha, a high Ecuadorian Andes lake, and SST reconstructions in the Warm Pool of the WEP and the Cold Tongue of the EEP provides three distinctly different pictures of ENSO history. The majority of these paleoclimate studies are hampered by their reliance on a single proxy and/or a single site. The results from General Circulation Models for climate have been similarly diverse, with studies using various models supporting one or another of the conclusions based on proxy data. [See the EAPS webpage <http://eapsweb.mit.edu/news/index.shtml> for a more detailed discussion that includes a figure with representative proxy records.]

Thus, last year several people came together [See Box 1 and Figure 1] to do something about this problem, and on September 1st 2004 we arrived at San Cristobal, Galapagos to get sediment cores from El Junco Lake [Figure 2] which we hope will contain the El Niño history of the entire last glacial cycle (150,000 years). During

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EAPSpeaks is published annually by the Department of Earth, Atmospheric and Planetary Sciences at MIT and is distributed to members, alumni/ae and friends of the Department. Please send any pertinent information or requests to Ms. Jacqui Taylor.

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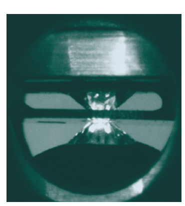
Dear Alumni/ae and Friends of EAPS

In my discussions with alumni/ae since becoming Department Head of EAPS a year and a half ago, I was surprised and impressed with the level of interest in what our Department is up to and where we're headed. This newsletter is an attempt to respond to that interest and it is my hope to convey some representative snapshots of the many activities that have made EAPS such an exciting place to study and work during the past year. Let me thank our Education Coordinator, Vicki McKenna, and Administrative Assistant Jacqui Taylor for their considerable efforts in making this newsletter happen. Research in EAPS spans from the deep interior of the Earth to the depths of space, as discussed in articles by faculty member Dan Shim and graduate student Doug Jerolmack. Our research and educational activities in weather and climate are exemplified in articles by undergraduate Christine Wood and faculty member Julian Sachs. In addition, Dan Burns reports on a tremendously successful symposium held last spring to honor faculty member Nafi Toksöz.

You may be interested to hear that EAPS will soon be getting some much needed space to accommodate our evolving research and education efforts. The Department has obtained a floor and a half of Building E25 and we will be vacating Building E34. The Earth Resources Laboratory, currently residing in E34, will return to the Green Building, and our faculty who use wet labs will relocate to the top floor of E25. I'll report more on these developments in the future.

Finally, let me thank all of you for your continued interest in and support of the Department. Please feel free to stop by for a visit if your travels bring you to the Boston area.

With warm wishes,
Maria Zuber



Diamond Anvil (pg 5)
Only the diamond-anvil cell can generate and hold the pressures of the Earth's lower mantle.

Survey Team (Cover, pg 8)
Will El Niños become more intense and/or frequent in response to global warming?

MER Experience

Douglas Jerolmack

With contributions by David Fike and Wes Watters

Although the principle focus of the Mars Exploration Rover (MER) mission is to search for physical and chemical evidence of water on the surface of Mars, modification of the landscape by aeolian (wind) processes has created enigmatic erosional and depositional features that have captured the attention of mission scientists. Considering that postulated aquatic environments disappeared billions of years ago, the dominant agent sculpting the martian surface since that time has been wind. Interpretation of water processes at rover landing sites requires deconvolving water-lain deposits and aeolian features. It is in this context that professor John Grotzinger invited me to participate

Jumping for Joy in the Mojave Desert to scout the area for features that might serve as an analogue for the intriguing coarse-grained ripples that we observed at Meridiani.

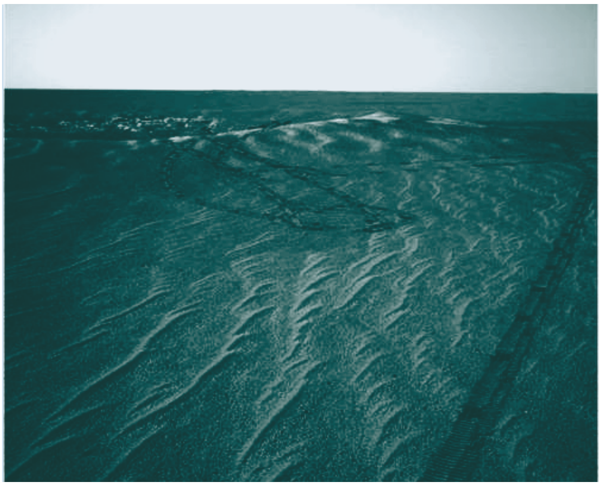
in the MER mission this past summer, which involved a one-month visit to the Jet Propulsion Laboratory (JPL) in Pasadena, California. My primary research focus as a Ph. D. student in EAPS is sediment transport on Earth, and in particular the formation of sand ripples and dunes in river, ocean and aeolian environments. While environmental conditions on Mars, such as atmospheric density and gravity, differ from Earth, the fundamental physical principles developed in terrestrial research should be applicable to Mars. Working with Professors David Mohrig and Maria Zuber, and Post-doctoral Researcher Shane Byrne, I have used topography and image data from satellites orbiting Mars to study large-scale sedimentary deposits that were formed by water. The data required to apply many techniques of sedimentology to martian landscape evolution, however, have not been available until the MER mission. The unprecedented detail afforded by high resolution imaging from the rovers allows analysis of shape, grain size and spectral properties of aeolian features, which are crucial for interpreting formative wind conditions and soil composition.

Meridiani Planum, the landing site for the rover Opportunity, appeared as a nearly featureless plain from orbit. The view from the surface is quite different however, as Opportunity has discovered a wealth of intriguing wind-formed features. My task at JPL was to survey all image data from Opportunity, with EAPS graduate students Wes Watters and David Fike (who are working also on other MER projects), and catalog and measure aeolian features that might be used to interpret wind-processes at the site. For example, small, coarse-grained ripples are ubiquitous on the plains (see picture). From the grain size of these ripples we can estimate the minimum surface wind speed at the time of ripple formation. The various orientations of ripple crest-lines reflect a change in wind direction. Another feature used to determine wind direction is eroded bedrock. Exposed rock at the rims of small craters on the plains is slowly being abraded away by wind-blown sediment, and more resistant iron-oxide spherules are weathering out of this bedrock. Behind these spherules are protected 'wind shadows', where bedrock has not been eroded as efficiently. As bedrock erosion is a slow process, these spherule 'tails' may be used to infer the long-term wind direction, and possibly the direction to major sediment sources. Active sediment transport has not been observed by Opportunity, and it is not known whether the formation of plains ripples and the erosion of bedrock is an ongoing process, or if these features reflect an ancient, blustery wind regime that is no longer present. One observable example of sediment transport at the Meridiani site is from satellite imaging, which reveals that bright streaks of airfall dust present around the rims of some craters are reoriented by the winds associated with large dust storms. The movement of dust implies that larger sand grains may also be mobilized during dust storms. The continuing health of the Mars rovers raises the exciting prospect that we may observe active sediment transport on Mars, as the dust storm season is now only a few months away.

The working environment at JPL is an exhilarating and challenging one. Mission scientists and their graduate students fill most of the 40 or more computers scattered across an open room, which is loosely divided into subgroups by placards hanging from the ceiling with labels like "Long term planning" or "soils". We work individually or in small groups on our mission-specific goals, trying to analyze the latest data and make a plan for the next day's science. Intermittent eruptions of excitement occur as particularly fascinating data come down from the rover, which immediately pops up on large projector screens for the whole room to see. In some cases all

Figure 1

Wind-formed ripples on the Meridiani plains, Mars, with rim of Eagle crater in the background and Opportunity in the foreground. Rover track is about 15 cm wide.



members of the team stop working to discuss the latest results. The day is also interrupted by numerous meetings where rover health is assessed, free-form science discussions occur, and the "long-term plan" (which usually involves only the next few days) is laid out. Progress on a particular project can be difficult in the presence of these distractions, but the environment ensures that individuals are reminded of their role in the big picture. The connection of ones project to the overall mission objectives keeps all team members motivated and engaged, and allows us each to broaden our scientific background. While the room is filled with experts of various disciplines, some new data is so surprising that it sends mission scientists running to the library to read up on a previously unimportant phenomenon that is outside their respective fields. One of the more memorable experiences of our work at JPL was a trip to the Mojave Desert to scout the area for features that might serve as an analogue for the intriguing coarse-grained ripples that we observed at Meridiani (see picture). While we had no success finding a specific analogue, we did have the opportunity to learn a lot about aeolian transport in the desert, including the subtle controls of topography on dune shape and grain size, and the wonder of hearing 'singing dunes' as sand avalanches down dune faces.

While most mission operations scientists have left JPL and returned to their home institutions, the rovers show no sign of quitting. New data is still coming down each day, and mission scientists communicate via teleconferences, and submit science plans remotely from workstations connected to JPL.

Many scientists involved in the project are relieved to finally be home, catching up with family and their own research, while graduate students resume their (generally non-MER related) thesis studies. I admit that progress in my own research is much more productive here compared to my time at JPL, but occasionally I yearn for those days of fast-paced science, with the collective excitement of a room full of scientists marveling at fantastic images from the surface of another world. ■

"The largest perturbation to global climate"

Journey to the deep interior of the Earth from MIT

by Sang-Heon Dan Shim

We have recently witnessed man-made robots exploring the Martian surface. However, the deep interior of the Earth, of which physical and chemical processes may affect the tectonics and even life on the surface, still remains largely inaccessible for us. Geologists and geophysicists have developed many different ways to study the deep interior: imaging the interior of the Earth using elastic wave propagation through the Earth interior, studying rocks and minerals from the deep interior, and performing computer simulations. In addition, mineral physicists have developed devices which enable them to generate pressure and temperature conditions relevant to the deep interior and to measure physical and chemical properties of minerals and rocks at the extreme conditions.

Among many existing high-pressure devices, only the diamond-anvil cell (Figure 1) can generate and hold the pressures of the lower mantle (700-3,000 km from the surface; 250-1,300 kilobars) and the core (3,000-6,400 km from the surface; 1,300-3,600 kilobars) of the Earth for sufficiently long time for the measurements of important physical and chemical properties of materials. In this device, a very small sample (typically less than 100 microns in diameter and 10 microns in thickness) is sandwiched between opposing faces (50-500 microns in diameter) of two gem-quality single crystal diamonds (1/4-1/3 carrat). The high strength of diamond and small pressed area allow experimentalists to reach as high as 5,000 kilobars. The modern diamond-anvil cells are extremely compact, and most of them are hand-held size. Force is normally applied using screws.

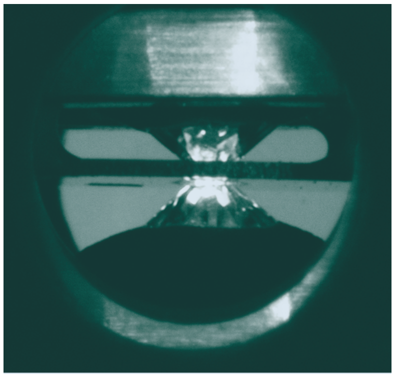


Figure 1

A sample and metal gasket assemblage sandwiched between two diamond anvils in the diamond-anvil cell. The height of a diamond anvil is about 2.5 mm.

Many heating methods have been developed to achieve high temperatures in the diamond-anvil cell. Powerful infrared lasers can heat samples up to as high as 6,000 kelvin which is comparable to the surface temperature of the Sun. Above 1,000 kelvin, the thermal radiation from the samples is sufficiently intense to be measured using spectrometers. Temperature of the sample can be estimated from the measured thermal radiation. Combining diamond-anvil cell and laser-heating techniques, entire pressure-temperature conditions of the lower mantle is readily accessible (Figure 2). However, the limit of the laser-heated diamond-anvil cell has not been fully explored. In fact, recent developments in synthetic diamond anvils and extreme high-power lasers are expected to expand the pressure-temperature conditions.

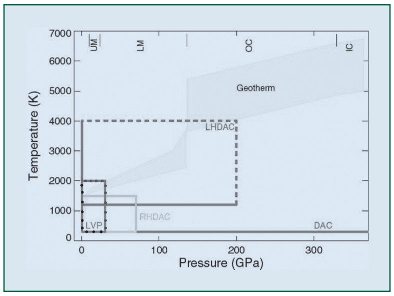


Figure 2

Pressure (100 GPa = 1,000 kilobar) and temperature conditions which can be generated by different high-pressure devices. For comparison, expected pressure-temperature conditions of the Earth interior is shown as the light gray area. DAC: Diamond-Anvil Cell, LHDAC: Laser-Heated Diamond-Anvil Cell, RHDAC: Resistance-Heated Diamond-Anvil Cell, LVP: Large-Volume Press.

Another important advantage of using diamond as an anvil material is that diamond is transparent to wide ranges of electromagnetic waves. This enables researchers to use various different probes, including x-rays and lasers, to measure the physical and chemical properties of materials directly under extreme pressure and temperature conditions. However, extremely small sample volume (< 0.0001 mm^3) in the diamond-anvil cell requires well focused, very bright beam sources. The third generation synchrotron radiation sources (Figure 3) provide extreme beam fluxes (more than 18 orders of magnitude, more photon fluxes than a typical laboratory x-ray tube source) with excellent collimation. This opens new opportunities to perform sophisticated measurements at the pressure and temperature conditions.

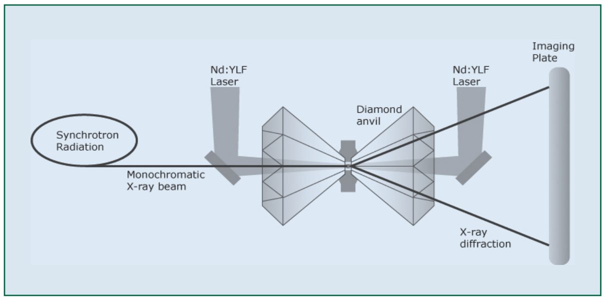


Figure 3

Schematic diagram of a combined synchrotron X-ray diffraction system with the laser-heated diamond-anvil cell.

I joined EAPS in June 2004 and continued my study of the crystal structures, physical properties, and chemical reactions of mantle silicates at the pressure-temperature conditions of the lower mantle using these technical developments in the third generation synchrotron facilities. For example, my collaborators and I showed that the globally observed seismic discontinuity at 660-km depth is related to the phase transition in a mantle mineral using the laser heating and high-resolution x-ray diffraction facility at Advanced Photon Source at Argonne National Laboratory (Shim et al., 2001a). The source of the 660-km discontinuity is an important constraint on the chemical composition of the lower mantle and material exchange between the upper and the lower mantle. While there has been a some experimental evidence supporting the phase transition hypothesis for the 660-km discontinuity, this result is the first confirmation directly obtained at the pressure-temperature conditions of 660-km depth. Later MIT seismologists led by Rob van der Hilst demonstrated that the density and velocity jump at the 660-km discontinuity is consistent with the phase transition model (Lebedev et al., 2002).

In recent measurements, we have extended pressure and temperature conditions to the boundary between the mantle and the core (1,300 kilobars and 2,500-3,000 kelvin) and measured x-ray diffraction patterns of the dominant lower-mantle mineral, $MgSiO_3$ perovskite (Shim et al., 2001b; Shim et al., 2004). We reported a significant change in the crystal structure of this mineral to so called "post-perovskite" phase (Shim et al., 2004). This result is consistent with the reports by other two groups in Japan (Murakami et al., 2004; Oganov and Ono, 2004). This transition has drawn much interest from seismologists and dynamicists because of its possible relevance to the seismic discontinuity at 2700-km depth and its possible influence on the mantle convection near the bottom of the mantle which many geophysicists have believed is the source of the plumes and the ultimate grave yard of subducting slabs.

My research group is continuing experiments at synchrotron facilities (Advanced Photon Source at Argonne National Lab, National Synchrotron Light Source at Brookhaven National Lab, Cornell High Energy Synchrotron Source at Cornell University) to better understand the crystal structures and phase relations of the post-perovskite phase and other lower-mantle minerals. We have also installed new laser spectroscopy and laser heating systems in our new high-pressure laboratory at the sixth floor of the Green Building at MIT. The laser spectroscopy systems measure the vibrational energy of atoms in the condensed phases (Raman spectroscopy), which can be used to identify phases, to study crystal structures, and to measure thermodynamic properties. Similar spectroscopy systems have been operated in many high-pressure labs for more than 10 years but limited to high-pressure measurements at room temperature. The most important improvement in our systems is that the systems can measure vibrational energies of atoms at in-situ high pressure and high temperature. The major obstacle at high temperature has been the thermal radiation of the samples which dominates in the visible spectral range where vibrational spectroscopy has been measured in conventional Raman spectroscopy systems.

Supported by MIT, National Science Foundation, and Jeptha H. and Emily V. Wade fund, I have built a dispersive spectroscopy system with a tunable laser (wavelength from 450 to 750 nm) and a time-resolved spectroscopy system with a nano-second pulse laser. Near ultra-violet laser lines shift the spectral ranges to short wavelengths where thermal radiation is relatively low below 1,200 kelvin. Nanosecond time-resolution spectroscopy is very effect to reduce detection of the thermal radiation effectively in vibrational spectroscopy at high temperature. This technique will be combined with the laser-heated diamond-anvil cell at our lab to study minerals at mantle temperatures (1,500-2,500 kelvin) for the first time.

The tunable laser spectroscopy system was completed in May 2004 and since then it has performed numerous measurements for hydrous minerals and oxides at high pressure. The pulse laser spectroscopy and laser heating systems are planned to be completed until summer of 2005. These spectroscopy systems are optimized to precisely determine the important phase diagrams of mantle silicates and oxides in the laboratory, which has been only possible at the third generation synchrotron facilities. These systems are extremely versatile and can be used for many different research projects. For example, their micro-beam (<5 microns) with a tight focal depth can measure the vibrational spectra of tiny inclusions in minerals without damaging the sample. Their imaging spectrometers can map the phases existing in rock samples. These systems can even evaluate precisely the quality of gem stones, such as diamond and ruby, in non-destructive way.

The high-pressure lab has 8 diamond-anvil cells, all of which can reach 2,000 kilobars. Also sample preparation and loading facility was completed in March 2004. The facility includes two micro-drill systems, which can drill 10-500 micron holes in metal gaskets, two high-resolution stereo-microscopes, and a cryogenic gas loading system. This sample preparation facility provides ideal environment for researchers to prepare, handle, and load micron-sized objects.

This new high-pressure facility is expected to stimulate interdisciplinary collaborations with existing strong groups in seismology, geodynamics, petrology, and geochemistry at MIT. Furthermore, this will also provide unique opportunities for MIT students to experience from theory to observation and experiment.

We will continue our effort to understand physical and chemical properties of minerals at deep-interior conditions by means of the state-of-the-art synchrotron and laser spectroscopy techniques. We will apply our experimental results to understand large-scale processes in the deep interior of the Earth. We are also interested in using our technology to understand the interior of other planets in the solar system. ■

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Atmospheric pressure is 1 bar. 1,000 kilobars is 14,500,000 psi. 100 micron is about 0.004 inch. Thickness of hair is about 50 microns.

Leah Hutchinson and Katherine Ricke, S.B. '04, Co-Winners of the Goetze Prize for Undergraduate Research.

Undergraduate Student Awards

Jessica Haurin, S.B. '04, was elected to the membership in Phi Beta Kappa.

Leah Hutchison, S.B. '04, was a co-winner of the 2004 Goetze Award for Undergraduate Research for her thesis, Determining Land Use Change and Desertification in China. This Award is made annually in memory of Christopher Goetze and recognizes outstanding undergraduate research in the earth and planetary sciences.

Katharine Ricke, S.B. '04, was a co-winner of the 2004 Goetze Award for Undergraduate Research for her thesis, Analysis of Biomarker Candidates from Plant Lipid Inputs into Galapagos Lacustrine Sediments. This Award is made annually in memory of Christopher Goetze and recognizes outstanding undergraduate research in the earth and planetary sciences.

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Reconstructing the History of El Niño from Galapagos Lakes

Julian Sachs and Rienk Smittenberg

Box 1

Paul Colinvaux, long-time Professor of Ecology at Ohio State University, now Scientist Emeritus at the Marine Biological Laboratory in Woods Hole, Massachusetts, is the first person to investigate and core the several lakes that exist on the Galapagos Islands in 1966. He had always wished to revisit these special islands, and to get fresh material to analyze with modern techniques that didn't exist 30 years ago.

Miriam Steinitz-Kannan, an Ecuadorian citizen and Regents Professor of Biological Sciences at Northern Kentucky University, was one of Paul's first students and has made a career specializing in Ecuadorian lakes. Without her efforts to organize permits and logistics, the expedition would not have succeeded.

Julian Sachs, Doherty Assistant Professor of Paleoclimatology in the MIT EAPS Department, has been working on ocean, lake, and bog sediments throughout the tropical Pacific in an effort to understand the response of the ENSO mode of climate variability to the climate background state. Rienk Smittenberg (kneeling), a Dutch citizen, arrived at Julian's lab as a postdoctoral fellow in August 2003 as a skilled organic geochemist from the Netherlands Institute for Sea Research. His skill, adaptability and good cheer in the field have been invaluable in retrieving the terrific sediment required for this research.

Mike Miller, Professor of Aquatic Ecology at the University of Cincinnati, is a long-time collaborator of Paul and Miriam's whose knowledge of limnology and ecology, and expertise in the field, were invaluable in the Galapagos.

El Niño torrential rains envelop the Galapagos, filling El Junco crater and causing the lake level to rise. During La Niña episodes—the opposite phase of the El Niño Southern Oscillation, when the eastern equatorial Pacific is dry and cold—the lake level falls. Paul Colinvaux cored these lakes in 1966 and showed that the upper organic rich 'gyttja' layer indeed contains a record of El Niño. Below that, he found red clay deposits which could not be dated at the time and which he interpreted as the weathering products of a dry crater. At ~5 m sediment depth, however, he found another organic rich band that was devoid of radiocarbon, and therefore > 40,000 years old, that thus could originate from the last interglacial. Now, we wanted to get fresh sediment to analyze with modern techniques like biomarker isotopic analysis.

We were staying in Hotel "Mar Azul", where we could use the abandoned restaurant area to spread out our equipment. The first day was spent hauling our gear over the crater rim to the lake edge. Fortunately there is a road that leads nearby the volcano top, so we didn't have to walk uphill for a day and camp out for the whole period in the cold and wet weather of El Junco. Indeed, cold and wet. As we knew beforehand, lake El Junco is most of the time enveloped by clouds, with relatively low temperatures, but still one has 'tropical' in mind when being right at the equator. Not so. Except for the few sunny hours we experienced, we ended up working in many layers of clothing and in full raingear for the 2-3 weeks we did our coring.

We performed the main coring using a piston corer operated from a raft consisting of two rubber dinghies and a platform. We also operated a home-made 'interface piston corer' to recover the upper sediment that is very liquid and easily disturbed. After some practicing - each lake is different - we mastered the technique and could retrieve good 'interface cores' of up to 70 cm, which we sampled in the field at 1 cm intervals. Below the upper three meters of soft organic rich Holocene sediment, the clay proved to be really defiant. It not only wanted to stay in the lake bottom, it was trying to keep the coring tubes that we send down to collect the clay. After twice losing a core barrel at around 4 meters sediment depth, we learned how to avoid that. Afterwards, we managed to get all our core barrels out, often with great efforts of hammering in, centimeter by centimeter, and 'corkscrewing' out, again centimeter by centimeter. On several days we recovered just two one meter sections. Several times

Figure 2
The El Junco lake occupies an explosion crater in the cone forming the 750 m summit of El Junco mountain, the highest point on San Cristobal island. It is enveloped for most of the year by the stratus clouds characteristic of the EEP climate. The lake is a closed basin and is fed only by rain falling directly onto its surface and on the narrow margin of the crater rim. A notch in the rim is clearly an overflow channel.

we needed to abandon the raft to let the raft buoyancy do the work for us. After a short three weeks, however, we had recovered close to 40 meters of sediment from 7 different sites in the lake, with the deepest hole about 12 meters. After this hard work, we could enjoy the beauty and unique flora and fauna of the Galapagos Islands for a couple of days, before returning home to start the real work.

It looks like our efforts paid off! The first visual impression of the split cores show that there are quite a number of darker bands within the clay, which likely reflect episodes of lake-filling from enhanced precipitation associated with El Niño, in contrast to dry periods when just red clay was deposited [Figure 3].

A high resolution record of El Niño throughout the entire Holocene will be constructed from these sediments by reconstructing precipitation and lake level variations from molecular (biomarker) δD and δ13C values, diatoms, spores, and elemental composition. Excellent chronologic control will be accomplished through multiple ^{14}C dates and ^{210}Pb analyses, and synchronization of cores with others in the same lake will be accomplished using magnetic susceptibility and density measurements, along with and visible and gamma-ray imaging. High-precision magnetic property analyses will provide additional chronologic control. Along with fresh cores a comprehensive collection of voucher samples of plant material, plankton and water was taken against which to verify and interpret our down core analyses. With a single source (rain) and sink (evaporation) of water, the D/H ratio of the water in El Junco Lake is sensitive to the balance between precipitation and evaporation. Owing to the higher vapor pressure of H_2O relative to DHO, evaporation enriches lakes and oceans in deuterium (D), while precipitation enriches them in hydrogen. During El Niño events, when torrential rains occur in the Galapagos Archipelago, we expect the lake levels to rise and the D/H ratio of lakes to decrease. Conversely, during La Niña episodes, the rain-starved lowlands of the Galapagos become tinder-dry and the normally rain-soaked volcanic peaks are moistened only by fog-drip from the enveloping stratus clouds, the lake level falls and the D/H ratio of the water is expected to increase.

We have started to analyze the organic-rich Holocene sediments, and they contain some of the lipid biomarkers we expected, and some we did not!. Determination of the hydrogen isp-topic ratio of algal lipid biomarkers from the sediment began in Dece-mber 2004. We have every ex-pectation that we will be able to reconstruct the first continuous record of ENSO-related preciptation variations from the eastern equatorial Pacific spanning at least the Holocene, and perhaps the entire last glacial cycle. We'll keep you posted on our progress. ■

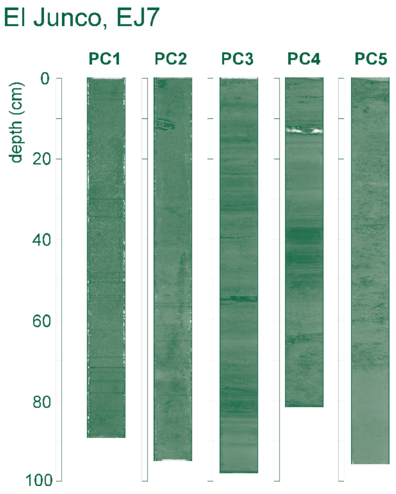


Figure 3
One of the split cores, EJ7, exhibits quite a number of darker bands within the clay, which likely reflect episodes of lake-filling from enhanced precipitation associated with El Niño, in contrast to dry periods when just red clay was deposited.

The M. Nafi Toksöz Symposium
A 70th Birthday Celebration
by Dan Burns

Attendees came from all corners of the world to honor Nafi Toksöz, a fixture in EAPS for almost 40 years, as he celebrated his 70th birthday. More than 175 colleagues, friends, and former students representing academia, industry, and governmental research labs filled the hall. The large number of EAPS alumni/ae attending gave the symposium the air of a wonderful reunion where old friends got reacquainted and new friends were made.

Frank Press, former Department Head, president of the National Academy of Science, and Presidential Science Advisor, was the first speaker at the first official function in the new Stata Center Auditorium on May 25, 2004 – the M. Nafi Toksöz Symposium; a celebration of Nafi's 70th birthday. The list of speakers was a who's who in geophysics over the past 50 years. In addition to Frank Press, the speakers included: Don Anderson (Professor of Geophysics at CalTech and winner of both the National Medal of Science and the Crafoord Prize), Sean Solomon (Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, a member of the MIT faculty for more than 20 years, and one of Nafi's first graduate students), Arthur Cheng (partner in Cambridge GeoSciences and one of Nafi's former students), Don Paul (Vice President and Chief Technology Officer of ChevronTexaco, member of EAPS Visiting Committee, and EAPS Alum), Wafik Beydoun (Negotiator in Total's E&P New Ventures& Asset Management Team and a former student of Nafi), Ken Larner (former Charles Henry Green Professor of Exploration Geophysics and Director of the Center for Wave Phenomena at the Colorado School of Mines, currently University Professor at CSM, and EAPS Alum), Oleg Mikhailov (recent EAPS Alum advised by Nafi, winner of the J. Clarence Karcher Award from the Society of Exploration Geophysics, currently working in international business development for ChevronTexaco). Speakers were introduced by a roster of notable scientists, including Freeman Gilbert, Neal Goins, Mike Fehler, and Dale Morgan.

Nafi first arrived at MIT in 1965

The symposium highlighted the incredible breadth of Nafi's scientific achievements in areas that include earthquake seismology, planetary interiors, tectonics, heat flow, exploration geophysics, and rock physics. Nafi's publication list includes more than 325 papers and several books, and he's still going strong. The length of Nafi's CV and publication list prompted one speaker at the symposium to comment that he needed a new ink cartridge in his printer just to print it.

Nafi first arrived at MIT in 1965 as an Assistant Professor of Geophysics having received his B.S. in geophysics (1958) from

the Colorado School of Mines, and his M.S. (1960) and Ph.D. (1963) in geophysics from the California Institute of Technology. He was appointed Professor of Geophysics in 1971, he designed and became Director of MIT's Wallace Geophysical Observatory in 1975, and he founded the Earth Resources Laboratory in 1982. He was the Director of ERL until 1998, and continues to be an active research leader at the Lab. Nafi has received scientific achievement awards from NASA, Colorado School of Mines, and the Los Alamos National Lab. His ability to discern solutions to complex problems and communicate his insights clearly and thoughtfully have made him a sought after speaker, consultant, and commentator in academia, industry, and the media. Nafi has been an innovative user of a wide range of technology to solve the scientific problems that interest him. He has been a leader in laboratory physical modeling and large-scale computational modeling to go hand in hand with fundamental

Director of MIT's Wallace Geophysical Observatory in 1975

theoretical derivations. Even more impressive is that Nafi continues to be a leader in all of these areas as he moves through his 70th birthday.

Nafi has also been a prolific and supportive advisor to graduate students in EAPS where he has advised more than 100 graduate students. In addition to his scientific guidance, he has always taken a keen interest in nurturing their careers. His graduates hold positions in industry and academia throughout the world, and he continues to be a resource to each of them with advice, mentoring, and friendship long after they've moved beyond our Department.

Following the technical symposium the attendees gathered for a dinner celebration at the Top of the Hub Restaurant overlooking the Charles River, the Green Building, and Fenway Park (where the Red Sox were hosting the Oakland Athletics - perhaps it was Nafi's birthday that put the Sox over the top this year?). The festive dinner ended with some good-natured roasting and some heartfelt good wishes as Nafi enters a new decade of scientific endeavors, student mentoring, and warm friendship. He was presented with a range of birthday gifts including framed photographs of his former CalTech classmates and the Houston Chapter of his graduate student alumni/ae. The final gift was a glass bowl engraved with the words that speak to Nafi's contributions to EAPS and MIT: "To M. Nafi Toksöz - outstanding scientist, mentor, and friend". EAPS is privileged to count Nafi Toksöz among its faculty ranks. ■

Founded Earth Resources Laboratory 1982

Degrees Awarded, 2004

	Thesis Title	Program	Advisor	Degree
Sinan Akciz	"Structual and Geochronological Constraints on the Ductile Deformation Observed Along the Gaoligong Shan and Chong Shan Shear Zones, Yunnan (China)"	Geology/ Geochemistry	Burchfiel	Ph.D.
Julia Baldwin	"Petrological and Geochronological Constraints on the Metamorphic Evolution of High-Pressure Granulites and Eclogitesof the Snowbird tectonic zone, Canada"	Geology/ Geochemistry	Bowring	Ph.D.
Bridget Bergquist	"The Marine Geochemistry of Iron and Iron Isotopes"	Chemical Oceanography	Boyle	Ph.D.
Michael Braun	"Petrologic and Microstuctural Constraints on Focused Melt Transport in Dunites and the Rheology of the Shallow Mantle"	Marine Geology & Geophysics	Keleman	Ph.D.
Yu-Han Chen	"Estimation of Methane and Carbon Dioxide Surface Fluxes using a 3-D Global Atmospheric Chemical Transport Model"	Atmospheric Science	Prinn	Ph.D.
Carolyn Gramling	"A Radiocarbon Method and Multi-Tracer Approach to Quantifying Groundwater Discharge to Coastal Waters"	Marine Geology & Geophysics	McCorkle	Ph.D.
Fernanda Hoefl	"Observations and Modeling of Wave-Acdelertion-Induced Sediment in the Surfzone"	Marine Geology & Geophysics	Elgar	Ph.D.
Peter Huybers	"On the Origins of the Ice Ages: Insolation Forcing, Age Models, and Nonlinear Climate Change"	Climate Physics & Chemistry	Wunsch	Ph.D.
Robyn Kelly	"Subduction Dynamics at the Middle America Trench: New Constraits from Swath Bathymetery Multichannel Seismic Dataan 10BE"	Marine Geology & Geophysics	Driscoll	Ph.D.
Astri Kvassnes	"The Evolution of Oceanic Gabbros: In-situ and Ancient Examples"	Marine Geology & Geophysics	Dick	Ph.D.
Ana Lima	"Molecular and Isotopic Records of Combustion Inputs to the Environment over the Last 250 Yrs."	Chemical Oceanography	Eglinton	Ph.D.

William "Lyons, III"	"Quantifying Channelized Subnmarine Depositional Systems from Bed to Basin Scales"	Marine Geology & Geophysics	Grotzinger	Ph.D.
Jennifer Matzel	"Rates of Tectonic and Magmatic Processes in the North Cascades Continental Magmatic Arc"	Geology/ Geochemistry	Bowring	Ph.D.
Brendan Meade	"Kinematic Models of Interseismic Deformation in Southern California"	Geophysics	Hager	Ph.D.
Kerim Nisancioglu	"Modeling the Impact of Atmospheric Moisture Transport on Global Ice Volume"	Climate Physics & Chemistry	Stone	Ph.D.
Lindsay Schoenbohm	"Cenozoic Tectonic and Geomorphic Evoltuion of the Red River Region, Yunnan Province, China"	Geology/ Geochemistry	Burchfiel	Ph.D.
Steven Singletary	"Igneous Processes of the Early Solar System"	Geology/ Geochemistry	Grove	Ph.D.
Henry Steele	"Investigations of Cloud Altering Effects of Atmospheric Aerosls Using a New Mixed Eulerian-Lagrangian Aerosol Model"	Atmospheric Science	Prinn	Ph.D.
Geoffrey Gebbie	"Subduction in an Eddy-Resolving State Estimate of the Northeast Atlantic Ocean"	Physical Oceanography	Wunsch	Ph.D.
Evelyn Araneda	"A Modificatoin of the Levenberg Marquardt Method"	Geosystems	Morgan	S.M.
Fabio Dalan	"Sensitivity of Climate Change to Diapycnal Diffusivity in the Ocean"	Climate Physics & Chemistry	Stone	S.M.
Amy Englebrecht	"Determination of Sediment Provenance at Drift Sites Using Hydrogen Isotopes in Lipids"	Chemical Oceanography	Sachs	S.M.

John Thomas Farrar	"The Evolution of Upper Ocean Thermal Structure at 10ON, 125OW during 1997-98 SM"	Physical Oceanography	Weller	S.M.
Bradford Johnson	"The Water Supply of the Vieux Fort Region in St. Lucia"	Geosystems	Morgan	S.M.
Christina Kaba	"Reconstructing Long Term Sediment Flux from the Brooks Range, Alaska using Shelf Edge Clinoforms."	Physical Oceanography	Mohrig	S.M.
Shinichiro Kida	"Eddy Dynamics of B-Plumes"	Marine Geology & Geophysics	Price	S.M.
Alison Klesman	"Comet-Asteroid Differentiation Using Visible and Near-Infrared Spectoroscopy"	Geosystems	Morgan	S.M.
Shawn Lawrence	"Kinematically Consistent, Elastic Block Model of the Eastern Mediterranean Constrained by GPS Measurements"	Geophysics	Hager	S.M.
Irene Lee	"An Analytic Examination of the Effect of the Stratosphere on Surface Climate Through the Method of piecewise Potential Vorticity Inversion"	Atmospheric Science	Plumb	S.M.
Valerio Lucarini	"Thermohaline Circulation Stability: A Box Model Study"	Climate Physics & Chemistry	Stone	S.M.
Erwan Mazarico	"Precise Orbit Determination of the Mars Odyssey spacecraft and geodetic inversion for the Martian gravity field"	Planetary Science	Zuber	S.M.
Ryan Merkin	"The Urban Heat Island's Effect on the Diurnal Temperature Range"	Temperature Range Geosystems	Prinn	S.M.
Joshua Neubert	"Lunar Lander Propellant Production for a Multiple Site Exploration Mission"	Geosystems	Morgan	S.M.

Recipients of Doctoral Degrees, June 2004, (Left to Right) Geoffre (Jake) Gebbie, Astri Kvassnes, Carolyn Grambling, Robyn Kelly, Julie Baldwin, Yu-Han Chen

Frederick Pearce	"Seismic Scattering Attributes to Estimate Reservoir Fracture Density: A Numerical Modeling Study"	Geosystems	Morgan	S.M.
April Russel	"Trojan Asteroid Spectroscopy and Space Weathering"	Geosystems	Morgan	S.M.
Miquela Vigil	"Star Formation In The Hii Regions Rcw 83, Rcs36, And Rcs 108"	Geosystems	Morgan	S.M.
Leah Windhorst	"Systematic Oversteepening in Longitudinal Profiles of Mixed Bedrock/Alluvial Channels at Tributary Junctions: Applachians, Virginia"	Geology/ Geochemistry	Whipple	S.M.
Lisa Lassner	"Determining an appropriate Tikhonov operator for Resistivity Tomography Inversion"	Marine Geology & Geophysics	Rondenay	S.M.
Leah Hutchison	"Determining land use Change and Desertification in China using Remote Sensing Data"	Earth, Atmospheric and Planetary Sciences	Hodges	S.B.
Katherine Ricke	"Analysis of Biomarker Candidates from Plant Lipid Inputs into Galapagos Lacustrine Sediments"	Earth, Atmospheric and Planetary Sciences"	Sachs	S.B.
Jessica Haurin	"Two-dimensional, Viscous Flow Modeling of Roll-back Subduction: Numerical Investigation into the Role of Slab Density in Subduction Dynamics"	Earth, Atmospheric and Planetary Sciences	Bowring	S.B.

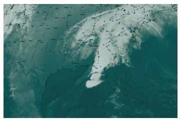
EAPS Team Wins Weather Forecasting Contest — Again!

by Christie Wood

MIT recently won the National Collegiate Weather Forecasting Contest (NCWFC) for the fourth year in a row. The team, comprising of undergrads, grads and faculty, competed for 20 weeks against more than 30 US colleges, forecasting the weather at 10 different locations. The competition is organized by Pennsylvania State University, which has one of the largest programs for undergraduate meteorology in the nation. But the team from MIT's Department of Earth, Atmospheric and Planetary Sciences—which has no major in weather forecasting—relies on its understanding of the dynamics of the atmosphere to out-predict its opponents. The team is led by Lodovica Illari who is a lecturer in meteorology. Last year's team members include Scott Stransky, Christie Wood, Cegeon Chan, David Flagg, Vikram Khade, Rob Korty, Greg Lawson, Jonathan Moskaitis, Nikki Prive, Mike Ring, Roberto Rondanelli, Steve Tobias, Masahiro Sugiyama, and Jeff Scott.

In addition to the forecasting team, Lodovica Illari offers an IAP class entitled Introduction to Weather Forecasting. Through this class, Illari and members of the forecasting team teach students the basic principles of synoptic meteorology and weather forecasting, and how to analyze hourly weather data and numerical weather prediction models. During the last week of classes the students test their new skills by participating in the class forecasting competition for Boston. Like members of the NCWFC team, they must predict the maximum temperature, minimum temperature and amount of precipitation for a given twenty four hour period. Also during the final week, there is a guest lecture by a noted Boston meteorologist which gives the students a chance to ask a professional about weather forecasting. ■

"relies on its understanding of the dynamics of the atmosphere to out-predict"



Participants in the 2003-2004 National Collegiate Weather Forecasting Contest. (Top) Mike RIng, Jon Moskaitis, Greg Lawson, Scott Stransky (Course 18), Rob Korty, Jeff Scott, Roberto Rondanelli, Steve Tobias (Course 2). (Bottom) David Flagg, Lodovica Illari, Lecturer, Nikki Prive, Vikram Khade. Missing from Photo Christie Wood (Course 18), Cegeon Chan and Masashiro Sugiyama.

Faculty Notes

Rick Binzel

Prof. Rick Binzel is performing telescopic observations of asteroids crossing the orbit of the Earth for the purpose of understanding their scientific connections to meteorites. By combining these observational studies with the discovery statistics for near-Earth asteroids provided by the MIT Lincoln Labs survey, Rick and EAPS Ph. D. graduate J. Scott. Stuart are refining estimates for the long-term impact hazard posed by these objects. He and his students are utilizing the NASA Infrared Telescope Facility on Mauna Kea, Hawaii to obtain near-infrared spectra of near-Earth asteroids to discern their mineralogy. Through the advanced technology of "remote observing", they are operating the NASA telescope from 10,000 km away in a laboratory control center in the Green Building. From MIT, an operator is able to control the positioning of the telescope and the acquisition of the data with full real-time monitoring and data analysis. By conducting observations from MIT, a greater number of students are able to participate than could be afforded in travel to the telescope.

Rick is also a Science Team member for the New Horizons mission to Pluto and the Kuiper Belt, with an anticipated launch in 2006. After a flight travel time of eight years, including a scientific and gravity assist encounter with Jupiter, New Horizons will fly past Pluto and its moon Charon enroute to the Kuiper Belt. He is engaged in the final stages of instrument design and mission planning and will be using both imaging and spectroscopic measurements to unravel the surface nature and evolutionary history of the ninth planet.

Sam Bowring

Prof. Sam Bowring has continued to work on two major themes, the origin and evolution of continental lithosphere and using high-precision geochronology to sequence the history of life.

Sam and his students are working on a spectacular exposure of lower crustal rocks in Saskatchewan where they are able to gain insight into the thermal, magmatic, and deformational history of the base of an Archean craton. This work has included the documentation of 1.9 billion-year-old eclogites (Baldwin et al; 2004). In addition his group continues their work on the evolution of the Kaapvaal craton of southern Africa using both surface exposures and lower crustal xenoliths to explore the thermal history of another Archean craton. They are also working on the evolution of 1.8-1.4 billion year old lithosphere in the southwestern U.S. Work here shows that structures locked into the lithosphere during growth have controlled subsequent thermal and mechanical perturbations. A project in Ireland and a project in the Cascade Mountains of Washington are using high-precision geochronology to understand time-scales of arc magmatism and specifically, the mechanics of making large igneous intrusions.

As part of Sam's long-term interest in sequencing the history of life on this planet, he has proposed a major new initiative entitled EARTHTIME. This project will create a virtual network of geochronology labs that will work together to push the limits of their techniques. This will require an unprecedented level of cooperation between labs but will make the sequencing of earth history at better than 0.1 % a reality.

Ed Boyle

Prof. Ed Boyle and his group have been working on trace element chemical oceanography and marine paleoclimatology. They have continued to trace the anthropogenic Pb transient in the ocean and in corals and sediments. They find that there is a distinctive pattern of evolution of Pb isotope inputs to the northeastern US due to the early (1840's) contribution from Upper Mississippi Valley ore deposits, so that Pb isotope patterns can be used to "date" sediments and deep ocean waters. The group participated in an NSF "Biocomplexity" project that is exploring the relationship between Fe and nitrogen fixation in the ocean; as a result of the field work with this program, they have been able to obtain surface and deep water transects for Fe in the western Atlantic Ocean (34 degN to 25 degS), and in the region from Hawaii to 175°W. Ed's group has also obtained the first data for Fe isotope ratio variability in marine plankton and the Amazon River system, and is also generating data on Zn isotope ratio variability in the human and marine environments. They have been generating a high-resolution (decadal-century resolution) U/230Th accumulation rate history of Bermuda Rise sediments between 30-140 kyrBP. This record is being used to provide a less arbitrary time scale and to evaluate the response of marine sedimentation to the "Dansgaard/Oeschger" glacial advances and retreats. They have been evaluating $SO4^{=}$ and Mg in foraminifera shells as tracers of carbonate ion and temperature. They have uncovered a surprising correlation between Mg (usually thought of as a temperature tracer) and carbonate ion, which must be investigated further to establish how reliable foraminiferal Mg is as a paleotemperature tracer.

Clark Burchfiel

Prof. Clark Burchfiel is just finishing his term as Past President of the Geological Society of America. His main research effort continues from 24 years of work in China and focuses on the tectonic evolution of the eastern part of the Tibetan plateau and regions to the southeast into Indochina. This work has been influential in developing general concepts of tectonics such as large-scale normal faulting during intracontinental shortening in the Himalaya and southern Tibet, and contributed a geological framework for gravitationally induced lateral flow from the high part of the plateau toward its margins. A second area of research has been in the Balkan region of southern Europe where the Cenozoic history of extensional tectonism has yielded a complex polygenetic evolution.

Jim Elliot

For the first time since 1988, Pluto's atmosphere was probed again with two stellar occultations in 2002. Data for the first event were recorded with two small telescopes and showed that Pluto's atmosphere had changed, but the data quality was not sufficient for further conclusions. Observations of the second event provided more extensive results. Data were recorded from nine telescopes, located in Hawaii, Arizona, and California at both visible and IR wavelengths (Elliot et al. 2003b). The most striking result was the marked difference between-the shape of the occultation light curves observed in 1988 and 2002. Sharp light-curve spikes were observed, which were barely detected in 1988. The spikes indicate dynamical activity in Pluto's atmosphere-caused either by waves, turbulence, or a combination of both. Based on the astrometric solution for the occultation (as derived from the light-curve timings from the different observing sites), it was determined that the atmospheric pressure had increased about a factor of two. For most of this time Pluto has been receding from the sun (perihelion occurred in 1989). The most likely cause for this pressure increase appears to be a warming of the N2 surface ice by about 1 K, which would then cause the requisite pressure increase in order to maintain equilibrium. Surface warming could be due to the effects of thermal inertia or a small increase in the amount of insolation absorbed by the surface ice.

More occultation opportunities to probe Pluto's atmosphere will occur in the next few years, as Pluto approaches alignment with the galactic plane. Some of these events can be observed simultaneously in the visible and IR when NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) becomes operational. Pluto's atmosphere will be probed by spacecraft as early as 2015, with the flyby of the New Horizons mission.

Kerry Emanuel

Prof. Kerry Emanuel began the 2004 academic year by flying on a NOAA WP-3D reconnaissance aircraft into Hurricane Fabian, as the culmination of a 3-year planning effort to obtain high-density data in the eyewalls of hurricanes. The object of this work is to estimate the air-sea fluxes of enthalpy and momentum under conditions of very high surface wind. Very little is known about such fluxes, yet they control the behavior of hurricanes. His approach was to deploy a very dense "picket fence" of GPS-based dropwindsondes .... small parachute-borne instruments deployed from aircraft that measure wind, temperature, pressure and humidity...thereby obtaining high-resolution profiles of wind and thermodynamic variables. From these, surface fluxes may be estimated as residuals of the angular momentum and entropy budgets. The research group set a new record for dropwindsonde spatial density and, owing to the need to correct an instrument problem, the amount of time any airplane has spent in the eye of a hurricane. They are now engaged in analyzing this data.

Working on an NSF ISTR project organized at MIT by Dennis McLaughlin (Civil Engineering), and with the aid of postdoctoral fellow Sai Ravela, the group developed a new algorithm for assimilating sparse data into complex models of fluid states that have highly nonlinear coherent structures. The new method, called "field alignment", locally remaps the prior estimate so as to preserve its structure while locating it correctly in space. This stands a good chance of solving a long-standing problem in data assimilation and thereby improving analyses and forecasts of complex fluid evolution, such as is found in the atmosphere and oceans.

Kerry's group began work on the very practical but important problem of hurricane wind risk assessment. Using statistics generated from historical hurricane track data, they developed a Markov Chain for generating synthetic tracks that have share important statistical properties with actual hurricane tracks. They can easily generate on the order of 104 synthetic tracks for each coastal location of interest, whereas the number of actual storms passing within, say 100 km of a given location is of the order of 101 or 100. They then run a deterministic hurricane intensity prediction model along each synthetic track, using the output to generate probability distributions of wind speed. This results in a calculatation of the frequency with which particular wind speeds will be exceeded in Boston, and 100 randomly selected synthetic tracks, compared to the track of Hurricane Bob of 1991.

Brian Evans

The Earth is a dynamic planet, and the properties of the rocks that compose it change over time scales that range from seconds (in earthquakes) to millions of years (during tectonic processes like mountain building). Similarly, because of the complexity and heterogeneity of the rocks, particularly those that make up the crust, physical properties may also depend on the length scale of observation. It is clear, then, that physical properties of porous rocks can be altered by a variety of diagenetic, metamorphic, and mechanical processes. Conversely, these processes can profoundly affect the transport properties of rocks, including fluid permeability and electrical conductivity, A better understanding of the processes that change porosity in the Earth is important, among other things, for improving resource recovery, predicting rates of metamorphism, understanding fault mechanics and fault stability, and estimating rates of deformation by pressure solution. Students, staff and faculty in the Rock Mechanics Laboratory at EAPS are working to understand the evolution of transport properties, including permeability and electrical resistivity, and of mechanical properties, including brittle fracture strength and the plastic flow strength. One important result that has emerged is that pore structures may be altered quite rapidly, geologically speaking. It is also apparent that the interlink between mechanical strength and pore fluids can operate to produce intense localization of deformation and instability of strength. The net result is a rich complexity of mechanical behavior that is documented in natural formations by such features as fault and shear zones, stylolytes and pressure selvages, veining, and compaction banding.

Raffaele Ferrari

Assistant Prof. Raffaele Ferrari's research efforts are directed at some of the major issues in understanding of ocean dynamics, its circulation, and role in the Earth's climate system. His approach necessarily involves observations, theory and modeling. He works at sea, constructs theories and uses numerical models where necessary. Much of the work falls into several broad, overlapping areas.

Ocean-atmosphere interactions. The ocean surface mixed layer is where communication takes place between the oceanic reservoir of heat, carbon dioxide, moisture, etc. and the overlying atmosphere in which we live. The exchange of properties, and their changes in time and space greatly influence not only the climate state, but also the biological productivity of the sea, sea-level change, and many other problems.

Present models of the upper ocean used for climate studies ignore the effect of lateral transport by oceanic eddy motions. Raffaele is the leader of the Climate Process Team on Eddy-Mixed Layer Interactions, a consortium with eighteen scientists from ten different institutions and two modeling centers, and whose primary goal is to obtain sufficient understanding of upper ocean processes that they can be properly included in climate forecast models. During this first year of work, he used a combination of data and high-resolution models to show that lateral processes modify substantially the heat budget of the upper ocean. Prompted by these results, closure schemes for these processes have been developed and are currently tested in large scale ocean models.

The role of the ocean on the Earth's climate. One of the most important contributions the ocean makes to Earth's climate is through its poleward heat transport. It is currently believed that a large fraction of this transport is associated with cold waters sinking into the abyss through convection at high latitudes. Raffaele and colleagues have recently challenged this paradigm and showed that the attention devoted to deep overturning circulations driven by convection is disproportionate to their actual role in the heat transport. A new view of the ocean emerges in which a surface intensified circulation dominates the poleward heat transport, rather than the deep overturning circulation. A noteworthy implication is that a collapse of the meridional overturning circulation might not drive abrupt climate change in the Earth's system.

Glenn Flierl

Prof. Glenn Flierl and his students are investigating physical and biological dynamics in the ocean and other more general problems in geophysical fluid dynamics. They have examined instabilities of time-dependent basic states, such as tidal flows or varying baroclinicity and are studying how these develop nonlinearly and create turbulent flows. In particular, time-dependent zonal flows which at no instant satisfy the necessary condition for instability of a steady flownevertheless can generate and sustain an active eddy field. The group is also exploring a simplified model of the Jovian atmosphere and shown that very weak vertical shears can lead to eddy formation and production of zonal jets. In the ocean, they are examining the aggregation processes for Antarctic Krill to understand the role of physical flows and behavior in creating patches on the scales of meters to kilometers. His research group anticipates that the size and age structure of the population, as well as food sources, ice geometry, and upwelling / downwelling may all contribute. Spatially intermittent distributions are an important element of krill ecology, and they believe that a better understanding of how the process works and how it evolved is essential.

Fred Frey

During 2003/2004 Prof. Fred Frey was a Joint Oceanographic Institution's Distinguished Lecturer presenting a talk titled "Formation of the Kerguelen Large Igneous Province, Gondwana Breakup, Lost Continents and Growth of the Indian Ocean" at 10 universities and colleges. The goal of this program is to educate students in regard to opportunities available in the newly initiated Integrated Ocean Drilling Program. This presentation is based on Fred's long-term efforts in studying the Indian Ocean; in particular, the Kerguelen Islands and ocean drilling cruises to the Ninetyeast Ridge, a hotspot track, and the Kerguelen Plateau, a very large igneous province on the Indian ocean floor.

John Grotzinger

During 2004 Prof. John Grotzinger was a Science Team Member for the Athena Mars Exploration Rover Mission. His roles included serving as a Geologist, as well as a leader of the Long Term Planning group for the Meridiani landing site. At this site, rocks are exposed along the rims of several impact craters and the rover (Opportunity) was able to collect geochemical, mineralogic, and textural data that showed the rocks were formed by precipitation from acidic brines. In addition, these data also indicate that the precipitated sediment particles were transported in the presence of flowing water. More recently, several EAPS graduate students in the sedimentary geology group have taken up this work in the extended mission phase, by mapping the eolian features at the Meridiani site. John and his students and post-docs are also continuing their studies of biogeochemical events at the Precambrian-Cambrian boundary in Oman and Namibia.

Tim Grove

Prof.Tim Grove and his colleagues are studying the Earth's most ancient (3.5 billion year old) preserved volcanic rocks to try to understand the thermal evolution of the Earth's interior through time. Their studies on komatiites from Southern Africa have shown that these rocks indicate that the Earth's mantle was only 150 to 250 oC hotter at 3.5 Ga than the Earth's mantle today. Their work also shows that the melting process that gave rise to komatiites is most likely analogous to the processes that occur in subduction zone environments – an island arc. In this setting water is released from the descending lithosphere and rises into hotter overlying mantle, which results in mantle melting. In the early Earth, they suggest that komatiites preserve evidence of this melting process. This is a controversial hypothesis, but it is gaining acceptance.

Brad Hager

Prof. Brad Hager's interests include numerical modelling of solid-state convection at high Rayleigh numbers; study of the Earth's gravity field; core-mantle coupling; space-geodetic observations of surface deformation; and dynamical processes in the interiors of the terrestrial planets.

Jim Hansen

It is self-evident that "good" forecasts are a necessary (but not sufficient) condition to demonstrate that one understands a process or a system. The degree to which - and the manner in which - forecasts fail provide exploitable information about what we don't understand. It is this that provides the basis of Assistant Prof. Jim Hansen's research interests; he aims to use forecasting as a tool to better understand a system. To this end he studies the seemingly disparate areas of modeling, forecasting, ensemble forecasting, verification, observation systems andobservation system design, data assimilation, quality control, model tuning, and the impacts of model inadequacy.

Jim's research is intrinsically interdisciplinary. Obviously, if one is interested in using forecasting as a tool to better understand a system then one must be knowledgeable about the dynamics and modeling of the system of interest, along with the possible implications of the assumptions that go into constructing a viable numerical model. Equally important is an interest in verification. Verification implies one is comfortable working with observations and understands their limitations, including non-traditional (but ever more prevalent and relevant) observations related to economics and health. Observations are also crucial for the specification of initial conditions, making data assimilation a central component of predictability. Issues in observations and data assimilation are even more tightly linked through quality control systems (deciding which observations to accept and which to reject) and through targeted observing systems (determining where to make supplementary observations using mobile observing platforms to maximally impact a future forecast).

A significant portion of his research portfolio consists of the generic, theoretical understanding of these different areas; one cannot properly interpret results from large, complex, and poorly understood systems without the understanding and insight provided by the simple, theoretical limit. His research group is currently exploiting these tools to better understand geophysical systems ranging from tropical cyclones (and the coupled tropical system in general) to the climate system at a range of time scales.

Tom Herring

Prof. Tom Herring is using global positioning system and very long baseline interferometry data to develop geophysically based models of changes in the rotation of the Earth and Earth deformations on global and regional scales. He is also using satellite based laser altimetry to study earth and ice sheet height changes.

The geodesy and geodynamics group in the Department is using high precision GPS measurements in many different study areas. These areas include the tectonic deformations over much of the southern Eurasian plate bounday, southen New Zealand and the western United States. Processes on time scales of years leading up earthquakes, days to years in the domain of post seismic deformation, and seconds for surface wave propagation during earthquakes, are all studied. The group is also involved in monitoring and modeling human induced deformations in oil fields. To support these activities and to improve even further the accuracy of GPS measurements, MIT has become a data Analysis Center for the International GPS service and acts as the GPS combination center for the Southern California Integrated GPS Network (SCIGN) [http://geoweb.mit.edu/~tah/SCIGN_MIT].

Kip Hodges

Much of Prof. Kip Hodges' current research focuses on the evolution of active mountain ranges. Research continues on the relationships among climatic, geomorphic, and tectonic processes in the central Himalaya in collaboration with Kelin Whipple. Along with their students, they have documented a previously unrecognized active thrust system near the the central Himalayan range front. This fault system poses substantial seismic risk for hundreds of thousands of people settled along its trace. Kip also has just begun a new project with Kelin Whipple to determine the uplift history of the Altiplano in southern Peru based on studies of the incision history of the two deepest canyons in the Western Hemisphere, those of the Cotahuasi and Colca Rivers. A third on-going project in the Ladakh region of northwestern India is aimed at providing constraints on the process of subduction of continental crust during collisional orogenesis. All of these projects (and more) are supported by Ar-Ar and (U-Th) /He mass spectrometry systems in MIT's Noble Gas Laboratory. Besides such practical applications, the Laboratory is home to a major effort to develop excimer laser microprobes for (U-Th)/He thermochronology.

Richard Lindzen

There are several areas where Prof. Richard Lindzen and his group are conducting research most, but not all of which is related to climate. 1. The determination of convective mass flux from geostationary satellite data. Geostationary data is ideally suited in terms of resolution and temporal continuity for the study of convection. On the other hand, this data is limited to the infrared and visible. For rainfall, microwave data would be useful, but the high orbit of geostationary satellites makes microwave measurements impractical with current technology. Past attempts using simply infrared brightness, have had only limited success in measuring rainfall, but our emphasis on relative brightness of cores vis a vis the higher brightness of surrounding cirrus decks appears likely to provide a better measure of cumulus intensity. Such a measure will be crucial for better evaluations of the Iris Effect, a potentially important negative feedback for climate wherein warmer temperatures lead to reduced cirrus. It will also provide a potentially more accurate measure of tropical rainfall. 2. The determination of meridional heat transport by the atmosphere. A primary distinction between various historical climate regimes has been the equator to pole temperature difference. Observational analyses suggest that the heat transport responsible for the equator to pole temperature difference is carried primarily by the atmosphere. However, our understanding, thus far, of what determines the atmospheric heat transport is limited. Their work suggests that such factors as the intensity of the Hadley Circulation (which provides the angular momentum to the subtropical jet whose instability gives rise, in turn, to the eddies which appear to be the agents of transport), boundary layer friction, and the inversions associated with ice covered surfaces, all play a significant role. They are in the process of quantitatively pinning down these various factors. 3. The investigation of the role of planetary scale baroclinic instability in the forcing of the Madden-Julian Oscillation of the tropics. The tropics display a prominent planetary scale westerly wave with a period of about 40 days. This is known as the Madden-Julian Oscillation. There is thus far no accepted explanation for its scale period or direction. They have noted that these are essentially the properties of planetary scale baroclinic instabilities associated with the subtropical jet stream. In cooperation with David Straus (of George Mason University) the research group has shown that there are significant correlations between the equatorial and subtropical phenomena. They are continuing to analyze the data and are attempting to determine how the extratropical wave influences the tropics. 4. The compilation of tidal properties associated with the primary planetary satellites in the solar system. Tidal phenomena have been associated with a variety of planetary problems ranging from the banded structure of Jupiter's winds, the retrograde winds of Neptune, to the requisite dissipation for the observed orbits of various satellites. In order to facilitate various planetary studies of these matters, they are compiling tables of the tidal potentials associated with the main satellites, and the expansions of these potentials in terms of the tidal eigenfunctions (known as Hough Functions) for the relevant planetary atmospheres. These eigenfunctions depend on the gross planetary properties (planetary radius, gravitational acceleration, planetary rotation rate, etc.) as well as the tidal periods.

Paola Malanotte-Rizzoli

Prof. Paola Malanotte Rizzoli and her collaborators have made important progress in the fields of data assimilation and tropical/subtropical interactions. In data assimilation an ensemble Kalman filter has been developed for a fully realistic primitive equation model of the tropical Atlantic, one the first applications of such a sophisticated method to an ocean general circulation model. The assimilation of TOPEX altimetry has allowed the reconstruction of the deep thermocline structure of the tropical Atlantic and its time evolution from the knowledge of surface data only. The results of the experiment have been used to assess the variability of the tropical Atlantic climate in the context of tropical/subtropical interactions. An important result of the analysis is that the seasonal cycle of the equatorial thermocline is modulated on an interannual (3 to 6 years) time scale by the water subducted in the subtropics in winter and advected by the shallow tropical meridional cells to the equator, where it upwells and modifies the meridional gradient of sea surface temperature. The latter one has a profound effect on the overlying atmosphere and on the rainfall over western Africa and Brazil.

John Marshall

Prof. John Marshall is an oceanographer interested in climate and the general circulation of the atmosphere and oceans, which he studies through the development of mathematical and numerical models of key physical and biogeochemical processes. He is director of MIT's Climate Modeling Initiative - see more here http://paoc.mit.edu/cmi/

David Mohrig

Assistant Prof. David Mohrig and his group continue studying processes controlling evolution of the morphology of the earth-surface system. This research is occurring over a full range of time and length scales and includes laboratory and numerical modeling, as well as collection and analysis of data from natural systems. Using a data set for the Pliocene and Quaternary sections of the Fisk Basin in the Gulf of Mexico, the group made the first direct measurement of time required to establish an approximately steady-state submarine landscape. Stratigraphy of the basin fill provided a long view of earth-surface dynamics, recording external forcings such as tectonism, climate and sea level that interacted with and were overprinted by internally generated fluctuations in the depositional system itself. Accurate reconstruction of these external forcings requires decoding the stratigraphic record into its externally and internally generated signals. Internally generated fluctuations for Fisk Basin average out with a characteristic time scale of 0.47 million years. This duration is large relative to time intervals for known variability in external forcings such as climate. For a second study of submarine landscapes the group has acquired high resolution acoustical data defining the bathymetry and subsurface geometry of the continental slope, offshore Brunei Darussalam. Networks of channels, both distributary and tributary-like in form, are being mapped and interpreted. Observed channel kinematics are being compared against results from group laboratory experiments where the connections between channel topography and channel-forming currents are unambiguous. The evolutions of these submarine networks are also be compared to evolutionary histories of better studied river-channel networks. Group research in the terrestrial environment has focused on evolution of sandy river bottoms and particularly on determining the role that interactions between dunes have in setting patterns of river-bottom sedimentation and erosion and in determining stage/discharge relationships. This study began with a series of laboratory experimentsdesigned to define how one bedform can interact with and affect another. Styles and rates of bedform interaction were determined to be very sensitive to the bedform topography itself and this sensitivity of bed deformation to boundary conditions is motivating the use of interface equations to describe an evolving river bed.

Dale Morgan

Prof. Dale Morgan's interests include geoelectromagnetism, inverse methods, appllied seismology and environmental geophysics.

Alan Plumb

Prof. Alan Plumb has wide interests in the dynamics of the atmosphere and ocean. The major focus of his group's work over several years has been the circulation of the stratosphere, in which eddy transport processes, through chaotic advection, dominate not only the large-scale circulation but also the global distribution of chemical components such as ozone. This research has involved theory, modeling, and participation in several airborne field experiments. More recently evidence has been accumulating that the stratospheric circulation has a significant influence on week-to-week, and longer term, variations of surface climate, through the so-called "annular modes," and Alan's group is currently investigating the dynamical mechanisms for this interaction. The formalisms developed for understanding and analyzing eddy transport in the stratosphere have broader applicability, and are now being applied to the ocean circulation, most recently to zonally reentrant flows such as the Antarctic Circumpolar Current. The objective is to develop an improved parameterization scheme for mesoscale eddies in low-resolution ocean models.

Another aspect of large-scale atmospheric dynamics research involves the dynamics of monsoon circulations. These circulations involve a complex interplay of moist atmospheric dynamics and land-sea contrasts. Alan's group has studied the characteristics of monsoon circulations in models using highly simplified continental geometries, focusing on the identification of overarching dynamical constraints on the circulation.

Ron Prinn

Prof. Ron Prinn, and his students and colleagues at MIT and the Marine Biology Laboratory, have recently reported results of several theoretical studies which highlight several significant interactions between ecosystems and climate driven by trace gas exchanges. Such interactions provide an important example of biocomplexity in the Earth System. Exposure to ozone decreased the net carbon uptake of U.S. forests and farmland in recent decades by about 10% making it comparable to climate change effects on these ecosystems. Emissions of the greenhouse gas methane from high latitude ecosystems over the past century are inferred to have major year-to-year fluctuations driven by climate variations and influenced also by soil organic compounds produce by vegetation. Estimation of month-by-month methane emissions, using global atmospheric methane observations and a transport model with assimilated meteorological observations, have defined seasonal cycles in wetland, rice paddy, and biomass burning sources, and concluded that rice emissions exceed, and energy-related emissions are less than, previous estimates. Studies of the effects of widespread dimethyl sulfide emissions from oceanic phytoplankton on the production of soluble atmospheric acids and salts, and hence cloud condensation nucleii, indicate the need for major additional chemical pathways to explain observations.

Stéphane Rondenay

Assistant Prof. Rondenay's group is involved in two key areas of solid earth seismology: (1) the acquisition of high-quality seismic data sets, and (2) the development and application of new teleseismic approaches to image structure in the earth's crust and mantle. The interpretation of resulting images yields new insight into the physical and chemical properties associated with internal geodynamic processes. For example, they are producing images of unprecedented resolution of the central-Alaska subduction complex and the Slave craton's lithospheric root. In addition, funding has been awarded to our group to undertake a major seismic instrumentation and imaging campaign of the Hellenic subduction zone.

Dan Rothman

Prof. Daniel Rothman and his group have made new theoretical advances in the fields of geobiology and geomorphology.

The work in geobiology concerns the dynamics of the long-term carbon cycle and its interaction with the evolution of life. Through analyes of the isotopic composition of carbon buried in ancient sediments, Dan and his colleagues have shown how major changes in the carbon cycle may have precipitated the "Cambrian explosion" of early animal life. This hypothesis leads to theoretical predictions for the evolution of the isotopic composition of specific organic compounds or "biomarkers." Tests of these predictions will be performed in collaboration with MIT colleague Roger Summons. The work in geomorphology concerns the physics of erosion due to subsurface "seepage" flows. Erosion by seepage is not only widespread on Earth but it is also thought to be responsible for many observed features of the Martian surface. Dan and his colleagues have constructed a laboratory model of the process. The experimental data reveal that that the erosion rate depends quadratically on the topographic gradient. The new theory is based on this finding. The resulting erosion dynamics, which has the form of a driven Burgers equation, quantitatively accounts for the shape of channels.

Leigh Royden

Prof. Royden's interests include regional geology and geophysics and the mechanics of large-scale continental deformation.

Julian Sachs

Assistant Prof. Julian Sachs and and his students, and post-docs study the mechanisms that cause climate to change on a variety of time scales ranging from decades to tens-of-thousands of years and how those changes are propagated through the interconnected ocean-atmosphere-ice system. In order to do this they develop paleoclimate records with very high temporal resolution from throughout the world's oceans and lakes. Molecular fossils and their hydrogen, carbon and nitrogen stable isotopic ratios provide estimates of past temperature, precipitation and biological productivity. Those observations can then be used to test mechanisms of climate change with numerical models. Through an understanding of the mechanisms that caused and propagated climate change in the past they hope to improve predictions of how climate might change in the future.

Sang-Heon (Dan) Shim

Assistant Prof. Dan Shim studies the Earth and planetary interiors by means of measurements at high pressure and high temperature. He is currently building a new high pressure lab at MIT. He has been recently awarded an NSF grant and Jeptha H. and Emily V. Wade Award for building a new combined Raman spectroscopy and laser heating system which they designed. This new technique will allow them to conduct spectroscopy measurements while the sample is compressed by diamond anvils and heated by high power laser beams. Through this method, they will measure the physical and chemical properties of planetary materials in his high pressure lab in order to understand the structure and dynamics of the Earth and planetary interiors.

Dan and his collaborators have recently reported their experimental results for an important mantle material directly measured at the pressure and temperature conditions of the bottom of the Earth's mantle. Their experimental result showed that the seismic change observed at the mantle and core boundary, which has not been well understood, may be due to the phase transition in the dominant lower mantle mineral. He also published his experimental results on Cr_2O_3 where he found new phase transitions at high pressure and high temperature.

Peter Stone

Prof. Peter Stone and MIT Research Scientists Chris Forest and Andrei Sokolov have updated their work using observed climate changes and anthropogenic forcings over the 20th century to constrain important uncertain climate parameters. In their earlier work, (Forest et al., 2002) they found that these observations did not significantly constrain the rate at which heat had been absorbed into the deep oceans during the second half of the 20th century. This rate needs to be known accurately if one is to make accurate predictions of future global warming. In their more recent results they have included natural forcings in addition to anthropogenic forcings, and now they obtain some useful constraints on the heat uptake. The new result indicates that many of the models are overestimating how rapidly heat penetrates into the deep ocean.

Roger Summons

The activities of Prof. Roger Summons' research group in the past year have focused on analysis and identification of biosignatures in organisms, microbial ecosystems and sediments as old as 2700 million years. They continue to study the intact polar lipids of marine cyanobacteria and a range of microbes from culture collections and extreme environments such as Yellowstone National Park and the Lost City hydrothermal vents of the Mid-Atlantic Ridge. Alex Bradley (Grad student). Gordon Love and Jochen Brocks, a Harvard Junior fellow working in Roger Summons' laboratory, have uncovered molecular evidence for a sulfidic ocean in the Mesoproterozoic. This adds weight to the hypothesis that the ocean transitioned from one that was iron-rich to one that was sulfide rich before finally becoming ventilated with oxygen at the very end of the Proterozoic. In studies of rocks from Australia and China, Gordon Love, Cao Changqun and collaborator Kliti Grice (Curtin University, Perth) have uncovered multiple lines of evidence for a Late Permian-Early Triassic ocean with sulfide in its surface waters. This provides strong evidence for natural variability being the cause of the PTB extinction rather than a meteorite impact. Roger continued his collaboration with Dan Rothman and John Hayes on the dynamics of the carbon cycle during major redox transitions of the ocean-atmosphere system (Late Neoproterozoic and Permian-Triassic Boundary). This work resulted in a paper, "Dynamics of the Neoproterozic Carbon Cycle" that was published in PNAS and formed the basis for a proposal that was funded by the Biocomplexity Program on Coupled Biogeochemical Cycles, NSF. They continued a major research contract with Petroleum Development of Oman studying organic matter from late Neoproterozoic sediments and their derived oils.

This project, which combines geochemistry with geochronology (Sam Bowring) and chemostratigraphy (John Grotzinger), is centered on sediments deposited during the radiation of the first animals.

Nafi Toksöz

Prof. M. Nafi Toksöz's research is directed into two broad areas: earthquake seismology and petroleum reservoir characterization. The major effort in seismology is the determination of crust and lithosphere structure by tomographic inversion of compressional and shear wave travel-times. He and his students have completed three-dimensional crustal models for China, and have started work on extending the study region to Central Asia, the Caspian, and the Caucasus.In the reservoir characterization area, Nafi's research is focused on induced seismicity and determining reservoir heterogeneities from the scattering of seismic waves. In petroleum or geothermal reservoirs, fluid production and injection change pore fluid pressure, resulting in strain changes that induce earthquakes. Induced earthquakes provide much information about reservoir properties, such as the stress regime, anisotropy, and fluid migration. Studying the nature of these earthquakes is also important for seismic safety since, on rare occasions, apotentially damaging earthquake can occur.The other area of study in reservoir geophysics is the utilization of scattered seismic waves for determining subsurface and reservoir heterogeneities. As being applied by research scientists Mark Willis and Dan Burns, and several graduate students, this approach is proving to be an important tool for characterizing the properties of "fractured" reservoirs.

Rob Van der Hilst

With a careful analysis of broadband seismograms Prof. Rob Van der Hilst and his co-workers revealed variations in mantle temperature and bulk composition below 1000 km depth under the northern Pacific and the Americas.

With a technique adapted from application in oil industry, they also began an ambitious effort to image in unprecedented detail the Earth's core mantle boundary; this effort is expected to change significantly our views on deep mantle processes and core-mantle interaction.

As part of the cross-cutting collaboration in the Department, Rob led a seismological field campaign in SW China; for a period of 1 year, an array of 25 seismograph stations has been recording earthquake signals to improve seismic imaging of mantle structure and understanding of regional tectonics and seismicity.

Ben Weiss

Assistant Prof. Ben Weiss' current research centers on magnetic studies of ancient rocks from Mars, the Moon, and Earth to understand the earliest behavior of planetary dynamos, the thermal histories of meteorites, impacts, and the evolution of life. He is currently focusing on several projects: developing measurement and inverse techniques for SQUID microscope imaging of remanent magnetization, inferring the history of the lunar magnetic field from measurements on glass spherules, conducting paleomagnetic studies of Archean rocks in Australia to constrain the evolution of the early terrestrial dynamo, climate and biomarkers, and studying the effects of shock on the magnetization of pyrrhotite and magnetite.

Kelin Whipple

Prof. Kelin Whipple's most recent research has been focused on discovering the degree to which direct coupling with feedback exists among climate, erosion, and deformation in Earth's crust. Previous analyses of the interactions between surface processes and tectonics, however inspiring, have left the strength of the coupling between climate and tectonics uncertain, and many questions unanswered. For example, it has remained unclear whether the details of the erosion processes are important to the geodynamic evolution of the mountain belt, and if so, how do they come into play? A recent paper published in the Journal of Geophysical Research (Whipple and Meade, 2004) is an attempt to answer these questions for the simplified case of a two-sided mountain belt at steady state (defined by a long-term balance between erosion and rock uplift). One central result that emerges is that the details of the erosion processes are critically important to the strength and nature of the dynamic coupling between climate-driven erosion and tectonics, controlling the sensitivity of mountain-belt width, topographic relief, and rock uplift rate to climatic and tectonic variables, and exerting a fundamental control on particle paths through the crust. The most important result in Kelin's view, however, is that we now know more clearly how and why the mechanics of river incision into rock matter to the evolution of mountain belts. The insights gained help define priorities for the continued study of the river incision process.

Jack Wisdom

Prof. Jack Wisdom's research interests include long-term evolution of the orbits and spins of the planets and natural satellites, qualitative behavior of dynamical systems, chaotic behavior and dynamics of planetary rings.

Carl Wunsch

Prof. Carl Wunsch and his group are increasingly employing the knowledge and tools of physical oceanography to understanding the record of past climate change. This work involves a combination of modeling, time series analysis, and theory. They are re-examining many of the basic hypotheses commonly used to explain climate variability, including the Milankovitch hypothesis and the spatial structures of changes.

Maria Zuber

Prof. Maria Zuber and colleagues completed development of a laser ranging device to be launched to Mercury. She assisted the Mars Exploration Rover team at the Jet Propulsion Laboratory in the assessment of landing sites and in risk mitigation in the landings. Her group also developed a new model of the crustal structure of Mars and developed a theoretical formalism to explain a dipole magnetic signature in a planetary crust in the context of remanent magnetization.

Faculty Awards

Brian Evans, was elected a fellow of the American Geophysical Union.

Paola Malanotte-Rizzoli, was selected as a member of the Faculty Advisory Committee for the search of the 16th MIT President.

Ben Weiss, was an Invited Speaker at the Seventh Annual Chinese-American Beckman Frontiers of Science Symposium, United States National Academy of Sciences and the Chinese Academy of Sciences, 2004.

Maria Zuber, was elected as a member of both the National Academy of Sciences and the American Geophysical Union.

Graduate Student Awards

Nick Austin, geophysics graduate student, received support for a GSA field proposal that was judged to be one of the best submitted this year.

Peter Huybers, Ph.D. '04, won the 2004 Rossby Award for his thesis, *On the Origins of the Ice Ages: Insolation Forcing, Age Models, and Nonlinear Climate Change*. This award honors Carl-Gustaff Rossby's many contributions both to science generally, and MIT in particular. Each year the selection committee determines the best PhD thesis done the preceding year within PAOC.

Joel Johnson, geolgy and geochemistry graduate student, received the Award for Excellence in Teaching from EAPS for his teaching during the Spring term.

Susan Kern, planetary science graduate student, received the Award for Excellence in Teaching from EAPS for her teaching during the Fall term.

Maureen Long, geophyscis graduate student, received the Award for Excellence in Teaching from EAPS for her teaching during the Fall term.

Arnico Panday, atmospheric science graduate student, received the Award for Excellence in Teaching from EAPS for his teaching during the Spring term.

Michael Person, planetary science graduate student, received the Award for Excellence in Teaching from EAPS for his teaching during the Spring term.

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