RICE

OUTCROPPINGS

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DEPARTMENT OF EARTH SCIENCE

MAGAZINE OF THE EARTH,
ENVIRONMENT,
AND ENERGY

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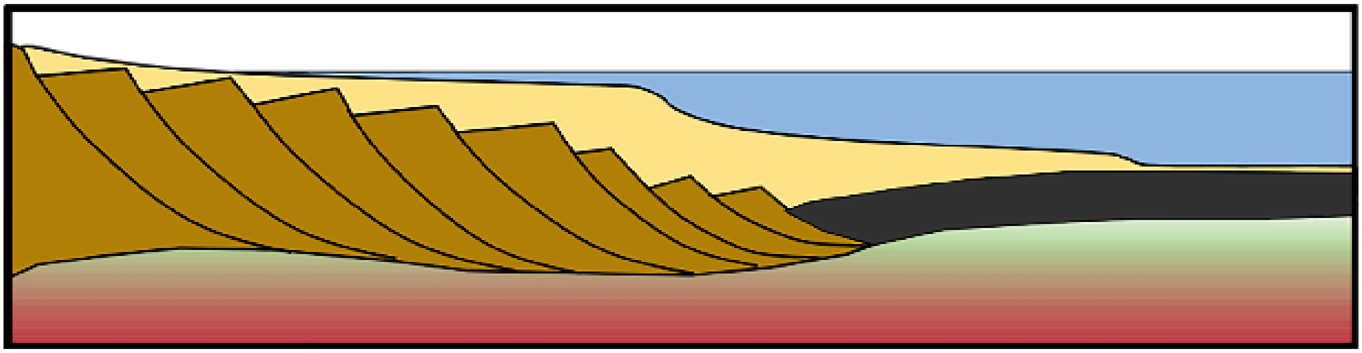

Industry – Rice Earth Science Symposia

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Continental Margins II:

Interdisciplinary perspectives on the building of a passive margin.

Re-examine and challenge past paradigms

- *sequence stratigraphy*
- *GIA, glacio- and tectono-eustasy*
- *magmatic versus amagmatic margins*
- *lithospheric and crustal evolution*
- *feedbacks within rift systems*
- *climate records*

Dinner keynote: sedimentology on Mars

Building a Houston-based think tank for outstanding problems in Earth, energy and environment.

Please join us for the pre-symposium reception for alumni and friends:

30 Sep, 2016
4 PM on the patio of the Department of Earth Science, Rice University

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Submissions of articles on Earth, environmental, energy or planetary science or their applications to policy and society are invited.

Articles, letters, alumni updates, and advertisements should be submitted to ctlee@rice.edu.

All submissions are peer-reviewed and edited for quality.

Welcome to the very first issue of Outcroppings

Our mission, as the department of Earth Science, is to increase understanding of our planet and environment. With this magazine, we hope to serve as the pipeline through which basic and applied scientific knowledge is disseminated to the broader community. There is a need for intimate dialog between Earth scientists and society. Problems in the natural world are fundamentally challenging. Natural systems are complex because there are so many interconnected components, with positive and negative feedbacks. Studying natural systems requires dealing with incomplete data sets, uncertainty, and complex systems. Such complexities are enough to turn most people away, but the reality is that complexities are the norm, not only in nature, but in how societies and economies operate. As Earth and environmental scientists, we excel at tackling open-ended problems and examine it from the perspective of a larger interconnected Earth system, helping us predict and anticipate new problems.

While many of our students have gone on to be academics or leaders in the energy industry, others have gone on to become medical doctors, government policy advisers, community organizers, or start their own businesses, fields of specialty that all require being comfortable with complex and evolving systems. Wherever students of Earth Science go, they take with them the much desired combination of critical thinking skills and the ability to see the big picture.

Front Cover: Bae Fong ESCI 334 Field Trip, B.S. Earth Science 2016. Photo Credit Jeffrey Piccirillo.

One goal of this magazine is thus to show examples of how Earth scientists think and how science is done. We will have articles focused on basic research. But unlike typical scientific articles, where only the answer is presented and the scientific process is portrayed as a mechanical template to be followed, we hope to provide insight into the actual process, the real, uncensored story of how science gets done. What were some of the mistakes or challenges? What were the "aha" moments? What were all the unexpected outcomes that turned out to be far more interesting than the original hypothesis or entirely changed the course of one's work? Who were the people that inspired one's ideas?

Another goal is to survey examples of how Earth scientists have gone on to influence our society. We will have first person accounts and interviews of Earth scientists who have continued on nontraditional paths. We will also highlight the hobbies or side interests of Earth scientists. Some are artists, skateboarders, musicians, carpenters, writers, gardeners, poets, and much more. Some find themselves in extreme environments, some will be astronauts.

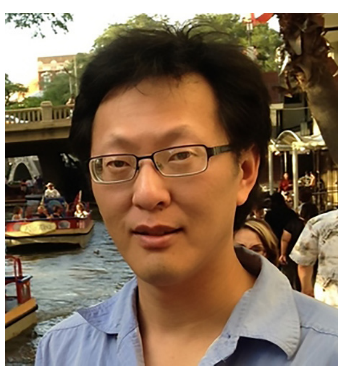
A third goal is to tackle controversial topics from a critical, but balanced and non-partisan way. All real world problems are complex. If we want to understand the origin of continents or how our atmosphere has evolved since the beginning of Earth, we have to recognize that there will be many competing views because the data is incomplete. Similarly, if we want to find a solution to our world's energy problems while at the same time find a way to mitigate negative environmental impacts, we have to accept that there are no perfect solutions and that whatever we do, there are risks that we have to evaluate. Solving such complex problems requires an open-minded mentality, where ideas, observations, and criticisms from all interested parties are considered.

We encourage readers to submit feedback and articles for upcoming issues. As we move along, the content and goals of the magazine will evolve as we learn from your feedback. We hope this is the beginning of a unique, interactive dialogue between Earth science and the community.

From the editors,

Cin-Ty Lee

Larisa LaMere ('16)



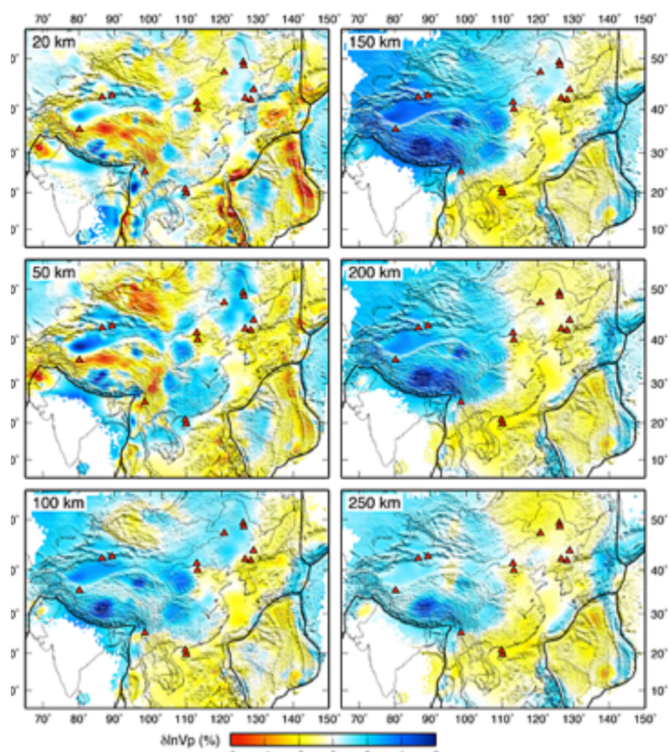
Research in the department 2015-2016

Research this past year took us on a wild ride, from deep within Earth's mantle, through the crust, into the oceans and atmosphere and onto other planets and beyond. Our research took us to almost all corners of our planet, leaving no stone unturned. Some of us studied rocks and volcanoes, while others studied the interactions between life and soils or simulated extreme conditions in our labs or on our computers. We investigated geologic processes on all timescales, from the billion year timescales of Earth's thermal evolution down to the rhythms of biological processes and earthquakes. We the editors have attempted to present a brief, but comprehensive overview of what our students, post-docs and faculty have been up to.

Deep lithosphere dynamics and the formation of continents

Formation and evolution of the crust and lithosphere appears to be a recurring theme among our faculty. Seismologists Alan Levander and Fenglin Niu have been actively writing up their results from seismic studies in Venezuela, western North America, China and the western Mediterranean. Jennifer Masy (PhD, '15) mapped out the deep lithospheric structure beneath the northeastern margin of Venezuela[1], Sally Thurner (PhD, '15) identified relic subduction structures beneath the Archean Trans-Hudson orogeny with US Array data[2], and post-doc Min Chen generated the most comprehensive and detailed tomographic map of the lithosphere beneath east Asia to date[3].

Graduate student Monica Erdman ('16), with Cin-Ty Lee and Alan Levander, reconstructed the density and compositional structure of the lower crust and lithospheric mantle beneath the Colorado Plateau in western USA and discussed implications for the rise of the Colorado Plateau[4]. Min Chen with Fenglin Niu reported a deep-seated origin for the high elevations of the Hangai Dome in Mongolia[5]. Graduate student Emily Chin ('13), with Cin-Ty Lee and Wiess visiting professor Janne Blichert-Toft, used Lutetium-Hafnium isotopes and modeling of diffusion kinetics to reconstruct the thermal evolution of the deep lithosphere beneath a continental arc. They showed that the tempo of arc magmatism is intimately tied to crustal and lithospheric thickening through effects on the thermal state of the asthenospheric mantle wedge[6]. Cin-Ty and former Wiess visiting professor Don Anderson also outlined the basic physics of how magmatic thickening of the crust and delamination feedback on each other[7].



P-wave velocity anomalies beneath China at different depths from Min Chen, Fenglin Niu and others[3]. Note the presence of large lateral variations in crustal velocity structure between the Tibetan plateau and eastern Asia. Note also the thick high velocity root beneath Tibet, corresponding to a thickened lithospheric root.

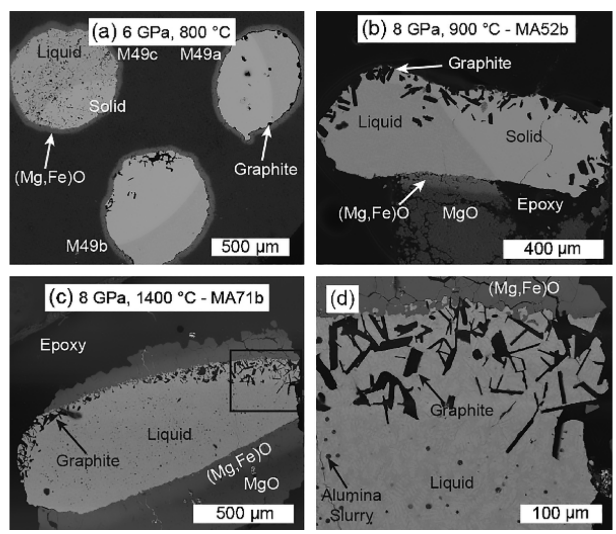
Oceanic lithosphere

Our faculty also found themselves investigating the structure of oceanic crust and basins. Emeritus professor Manik Talwani led a new tectonic model for the origin of the Bay of Bengal and Bangaladesh in the Journal of Geophysical Research. Specifically, Manik suggests that much of the basement beneath Bangaladesh is oceanic crust, on top of which lies thick sediments derived from the Himalayan orogeny. Thus, the ocean-continent basement transition here lies well inboard of the current passive margin. Visiting professor Jianping Huang, with Fenglin Niu and Richard Gordon in a creative paper, used water column reverberations to map out the focal depth of earthquakes in the oceanic crust to show that the stress state of the crust changes with depth[8], in apparent support of Richard Gordon's hypothesis that thermal contraction plays an under-appreciated role in internal deformation of oceanic plates[9]. Richard Gordon and Gregory Houseman used finite element modeling of thin viscous sheets to simulate the nature of deformation in diffuse oceanic plate boundaries, arriving at an improved view of the rheology of the oceanic lithosphere[10].

Dale Sawyer and Julia Morgan are writing up results of a large seismic study of the Galicia margin, an amagmatic continental rift in the eastern Atlantic, off the coast of Spain. Sarah Dean ('14) reported the results of seismic reflection experiments, showing that the structure of this amagmatic continental rift resembles a metamorphic core complex[11]. Dale and Juli, with international colleagues, also published a paper in Nature that showed that much of the lithosphere had been serpentinized, and with these constraints on the extent and nature of serpentinization, they offered new insights into how much water might be fluxed into oceanic lithosphere during continental rifting[12], which in turn has implications for how water gets recycled back into the Earth by subduction.

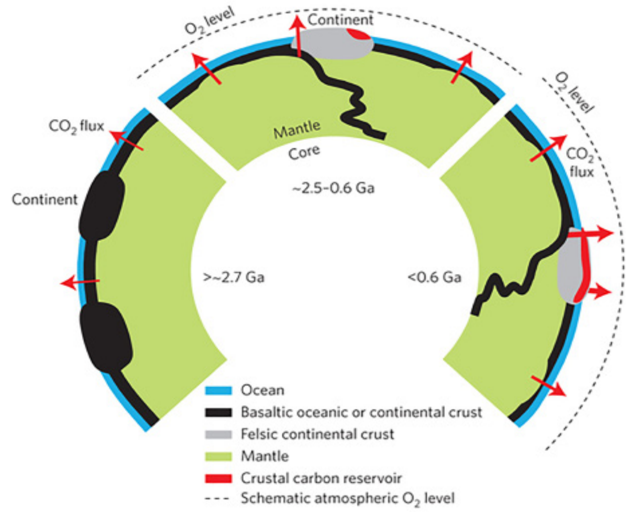
Whole Earth volatile cycling and the evolution of planetary atmospheres

And that brings us to our research on whole Earth volatile cycling. Rajdeep Dasgupta's group continues to be one of the world's leaders in this theme. Megan Duncan ('16) calibrated how the solubility of carbon dioxide varies with pressure and temperature in rhyolitic melts[13], which may have profound implications for the fate of carbon in subduction zones. Along these lines, current student Laura Carter published on the interaction between basaltic magmas with limestones, quantifying how much carbon dioxide might be released under such conditions[14]. Cin-Ty Lee and Jade Star Lackey at Pomona College described the implications of magma-wallrock interaction in continental arcs for long term climate evolution[15]. These works represent part of an ongoing 4 million dollar National Science Foundation funded project on the importance of continental arc magmatism on driving greenhouse conditions led by Cin-Ty Lee, Rajdeep Dasgupta, Adrian Lenardic, Gerald Dickens, and colleagues at Pomona College, University of Hawaii and UT Austin (arc2climate.org). Over the last year, they extended the project beyond its initial objectives. For example, Kyusei Tsuno and Raj dove into the deep carbon cycle, exploring equilibrium phase relations in the upper mantle for systems containing Fe, Ni, C, S and Cu[16]. This work led to a better understanding



Examples of experimental run products from Dasgupta's high pressure petrology laboratory. These are electron back-scattered images of experimental runs at 6 and 8 GPa (or 180 and 240 km depth), showing phase assemblages in a system containing Fe, C, Ni and S[16].

of the genesis of certain types of diamonds and their inclusions. Cin-Ty Lee, with Laurence Yeung and Adrian Lenardic, in a paper published this year in Nature Geoscience, zoomed outwards to present a new model for the whole Earth carbon and oxygen cycles, which explains how the Earth's atmosphere became oxygenated[17]. Finally, Echo Ding, with Rajdeep and Cin-Ty, re-examined the behavior of S in Martian meteorites of igneous origin to show that S contents reflect mixing between magmas and cumulates, hence caution is warranted when estimating the flux of mantle-derived S to the Martian surface from meteorites[18].

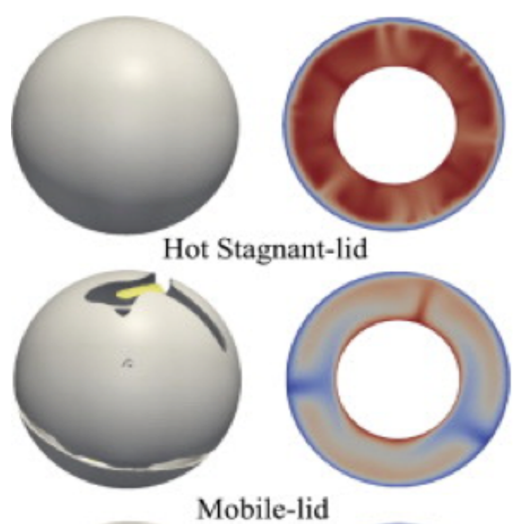


One explanation for the rise of atmospheric oxygen from Lee, Yeung and Lenardic[17]. A change in crustal composition around 2.5 Ga resulted in a decrease in the efficiency of the oxygen sink, allowing atmospheric oxygen to rise. Build-up of carbonate on the continents through time led to an increase in metamorphically derived degassing of carbon dioxide, resulting in more burial of organic carbon and production of oxygen.

Into the deep Earth

No understanding of whole Earth volatile cycles would be complete without constraints on the composition, structure and dynamics of the deep Earth. Post-doctorate Yuan Li, with Rajdeep Dasgupta and Kyusei Tsuno, were hard at work mapping out carbon solubility and partitioning in iron metals, with implications for the formation of the Earth's core and early degassing of the Earth's mantle, just after planetary accretion[19]. Fenglin Niu and colleagues continue to investigate the topography of the 660 km depth discontinuity, this time beneath northeast China, where they map out regions of slab stagnation and associated gaps and discuss potential links with volcanism[20].

On a much larger scale, Adrian Lenardic, our resident geodynamicist, has been mapping out the variable space over which different types of convective states can exist on Earth, ranging from plate tectonics to a stagnant lid regime to a regime in which heat is lost via heat "pipes" through the lithosphere[21]. Matt Weller ('15) and Adrian explored the role of internal heating and climate on the nature of convection, specifically showing that the Earth could be characterized by more than one type of steady state[22]. The implication is that Earth's current state of plate tectonics need not have been inevitable. If its starting conditions were different, it may have ended up in a different convective state; specifically, plate tectonics may be an intermediary phase, not an endmember state[23,24]. Adrian, with colleagues, continued exploring the role of different variables, such as the Urey number and lateral variations in stress state on the initiation of plate tectonics[25]. We have much to learn about how Earth's thermal state evolved and how it differentiated, but these works provide us with important new directions to follow.



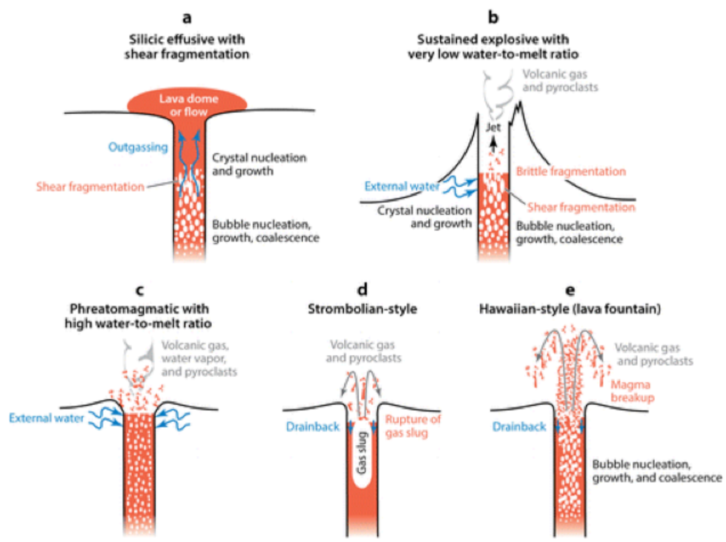
Numerical modeling results of three different types of mantle convection regimes. The mobile lid regime is akin to plate tectonics. However, a convecting mantle does not necessarily guarantee plate tectonics. Stagnant lids, e.g., a one plate planet, are permissible under certain conditions[22].

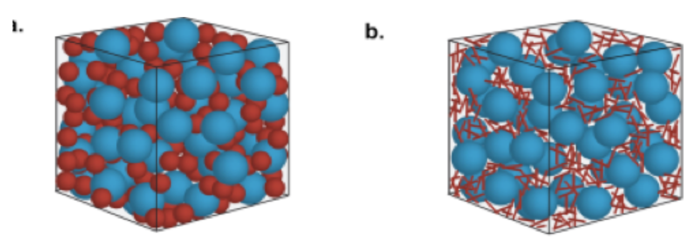
Magmas, plutons and volcanoes

Traveling from the deep mantle to the surface falls in the realm of magmas and volcanoes. Although to first order, we know how the mantle melts and how melts are transported, our faculty continue to ask new questions and push the boundaries. Ananya Mallik ('14) with Rajdeep Dasgupta explored the reaction of hydrous rhyolitic melts with ultramafic mantle, showing that such interaction can lead to flux melting and the generation of the unusually potassium rich magmas that are occasionally found in arc settings[26]. The passage of melts through the asthenosphere and lithosphere leads to refertilization, which Cin-Ty Lee and visiting scientist Jianping Zheng showed could destabilize continental lithosphere[27]. Exactly how much of the mantle is composed of unusually fertile domains is unclear, but past post-doctoral fellow Veronique Le Roux, with Rajdeep and Cin-Ty, proposed a systematic way of identifying such lithologies from the transition element compositions of lavas[28].

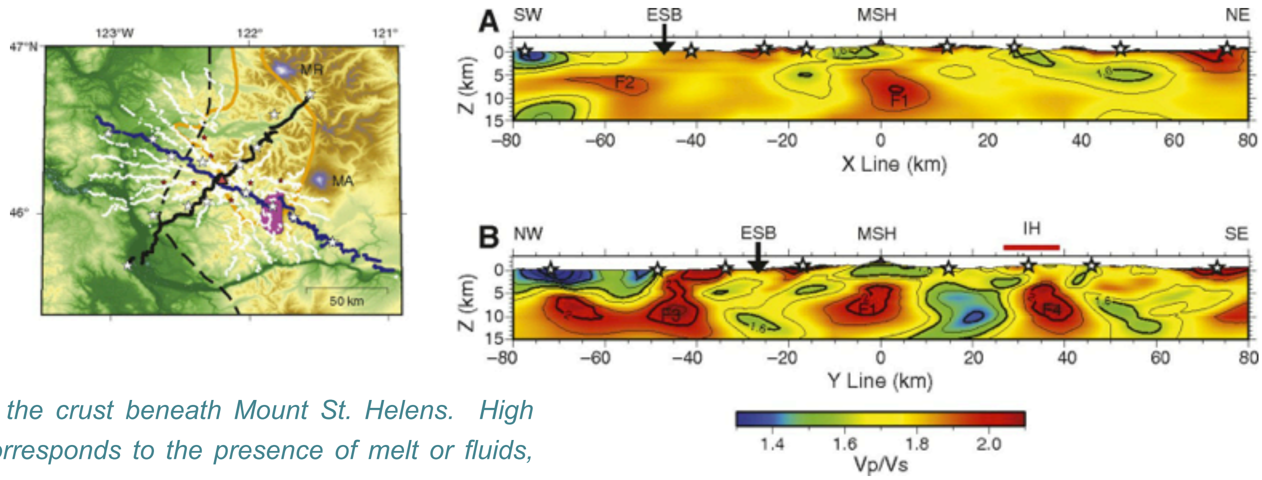
How these magmas make it out and erupt to form volcanoes or segregate to form plutons and batholiths may seem obvious. Melts are low density so they rise, but the devil is in the details. Not surprisingly, Helge Gonnermann presented definitive reviews, in the Encylopedia of Volcanoes and Annual Reviews of Earth and Planetary Sciences, of how magmas dike their way up[29] and then fragment[30]. Pranabendu Moitra ('15) and Helge, through analog fluid dynamic experiments and models, developed comprehensive parameterizations describing the role of non-uniform shaped and sized crystals on the rheology of magmas, a fundamental parameter in controlling magma flow and bubble dynamics[31].

Also important for understanding how magmas erupt is the role of degassing and bubble formation, which depend on the initial volatile content of the magma. Post-doctorate Thomas Giachetti and Helge conducted thermogravimetric analyses of pyroclasts to develop criteria for distinguishing between primary and secondary water contents, possibly forcing reinterpretation of past studies from the community[32]. On the plutonic side, Cin-Ty along with graduate students Michael Farner and Pranabendu Moitra showed how nonlinear latent heat release buys time, at the right time, for viscous silicic melts, like granites, to segregate from crystal-rich magmas[33]. Cin-Ty's group also developed new ways to determine the critical melt porosity for crystal-liquid segregation during crystallization of a magma and during partial melting of metamorphic rocks[34, 35]. Finally, one of the most recent developments in our departments is the I-MUSH seismic experiment centered on Mount St. Helens in the Washington Cascades led by Alan Levander's group. Post-doctoral fellow Eric Kiser, along with Alan and Colin Zelt, published results of their seismic survey in Geology, where they showed that the magmatic plumbing system beneath Mount St. Helens is a complicated network of magmatic mushes and cumulate bodies, the latter of which may influence the direction of magma transport[36]. All in all, we clearly have quite an interdisciplinary team at Rice working on magmatic systems.





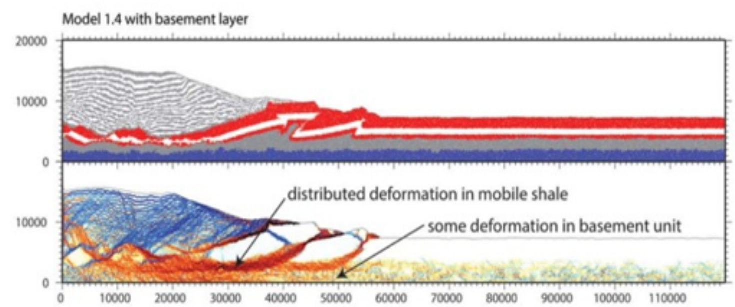
Above: Different styles of volcanic eruptions, summarized by Gonnermann[30]. Below: Analog models for crystal suspensions in magmas. Maximum packing efficiency is sensitive to particle size distribution and shape. Rheology of the magma is highly dependent on the nature of packing and particle shape/size[31].



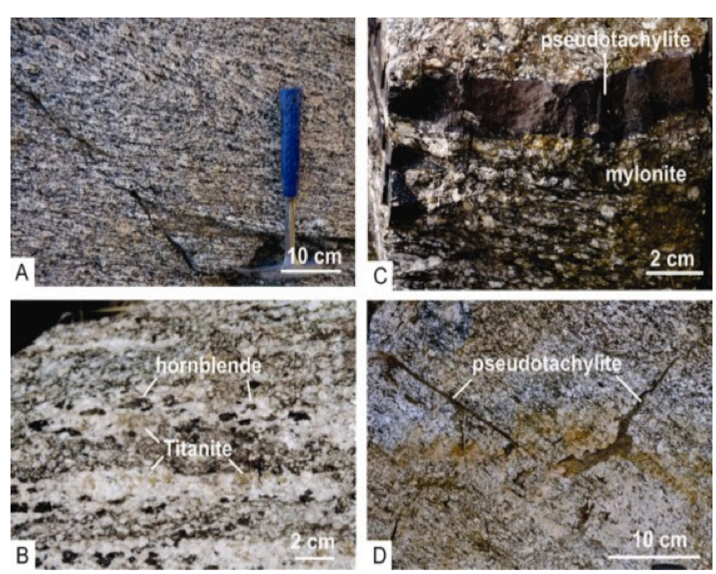
Vp/Vs structure of the crust beneath Mount St. Helens. High Vp/Vs generally corresponds to the presence of melt or fluids, such as might characterize a magmatic mush. Low values may correspond to cumulates[36]

Building mountains and following the sediments to the ocean

Mountains are transient. Their elevations are a balance between mountain building forces and the processes that take them down, from erosion to lower crustal gravitational collapse. Much excitement followed an interdisciplinary seminar on mountain building in the spring of 2014, which brought students together with John Anderson, Rajdeep Dasgupta, Cin-Ty Lee, Alan Levander, Carrie Masiello, Julia Morgan, Fenglin Niu, Laurence Yeung, and Wiess visiting professors Francis Albarede, Janne Blichert-Toft, Onno Oncken, and Yusuke Yokoyama to tackle the big problems in the origin and evolution of mountains. Cin-Ty Lee, Sally Thurner ('14) and post-doctoral fellow Wenrong Cao outline the feedbacks between magmatism, uplift, erosion and isostasy in controlling the rise and fall of volcanic arcs, discussing also how chemical weathering and climate respond[37]. Sarah Dean ('14) and Julia Morgan used discrete element numerical modeling to investigate the role of weak zones, such as layers of shale, in modulating the dynamic morphology of mountain belts in fold-and-thrust regimes[38]. Hehe Jiang, Cin-Ty Lee, Julia Morgan and visiting undergrad Catherine Ross investigated pseudotachylites – paleo-earthquakes- from a Cretaceous continental arc to track the interplay between thrust faulting, magmatism and erosion in the building of a magmatic arc[39].

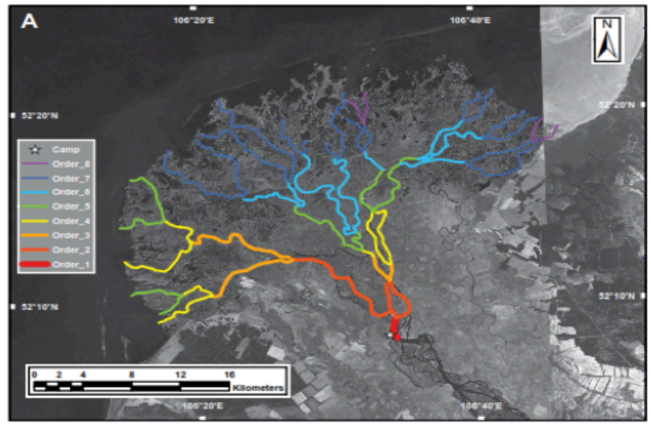


Results of discrete-element modeling of an orogen with an initially weak shale layer (gray in top figure). Bottom figure shows magnitude of strain, corresponding to faults and ductilely deformed regions[38].



Right: Mylonites and pseudotachylites from the eastern Peninsular Ranges Batholith, California. Composition of the pseudotachylite indicated that they represent preferential melting of biotite-rich layers[39].

As the sediments move down, we enter the realm of sedimentology. Graduate student Tian Dong and Jeff published a paper in the Geological Society of America Bulletin on the morpho-dynamics of the Selena river[40], which flows into Lake Baikal in eastern Siberia, the deepest freshwater lake in the world. This area is the best modern analog for deltaic evolution during sea level regressions, owing to the tectonic down-dropping of the Baikal rift. Tian and Jeff tracked gravel transport and may have come up with the definitive explanation for what controls gravel terminations in rivers: bifurcation in deltaic systems results in a rapid drop in the flow energy of higher order channels, resulting in rapid decline in gravel carrying capacity of rivers[40]. Jeff was also part of a study investigating flow and sediment transport in the Mississippi river in the vicinity of bedrock to alluvial transitions, with implications for engineering man-made structures in the river[41]. Finally, Andre Droxler was part of a study investigating sediment delivery off the continental margin and into the deep sea of the Gulf of Papua, the receiving basin for massive sedimentation coming off the actively uplifting Papua New Guinean orogeny[42]. From source to sink, our faculty are providing a comprehensive view of our surface environment.



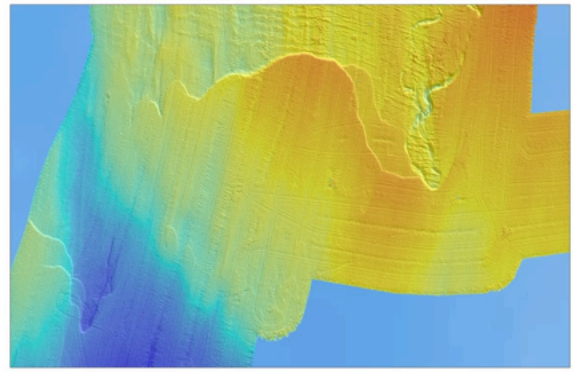
Tian Dong and Jeff Nittrouer showed that channel order in deltaic systems plays a key role in sedimentary transport dynamics[40].

Antarctic ice sheets and far-field signals of glacial cycles near the equator

For several decades, John Anderson's group has been investigating the history of the Antarctic ice sheet by studying the sedimentary record on the Antarctic shelf. Anna "Ruthie" Halberstadt ('15), along with post-doctorate Lauren Simkins and John Anderson used high resolution multibeam bathymetry data to map ancient glacial landforms in the Ross sea, showing that bed physiography played a key role in ice sheet dynamics[43]. Becky Minzoni ('15) and John Anderson compared for the first time the glaciomarine sedimentary record in the Antarctic Peninsula to local ice core records of temperature to reconstruct the history of the Antarctic ice sheet in the context of temperature[44]. Rodrigo Fernandez ('13) and John Anderson used sedimentary and marine geophysical data to reconstruct alpine glacial erosion rates from Patagonia, South America and the Antarctic peninsula[45]. They showed that glacial erosion, averaged over millennial timescales, decreases with increasing latitude, which they attribute to a general decrease in temperature and water availability.

This past year was also graced by the first application of compound-specific carbon 14 dating on glaciomarine sediments off of Antarctica. Published in the Proceedings of the National Academy of Sciences, Yusuke Yokoyama, 2014 Wiess visiting professor, worked with John Anderson to precisely date the collapse of the Ross Sea ice shelf to 5 ka, providing much needed chronological constraints on paleo-ice sheet dynamics[46]. Brandon Harper ('14) and Andre Droxler teased out the intricacies of carbonate platform development and sediment composition during glacial and interglacial cycles along the Great Barrier Reef off of northeast Australia[47]. Perhaps the most impressive piece of work from our faculty this past year might well be John Anderson's monumental summary of all the work he and his students over several decades have done on Quaternary sediments along the edge of the Gulf of Mexico. Together with Davin Wallace, Alex Simms, Antonio Rodriguez, Robert Weight, and Patrick Taha, all graduate students of John's from the last 15 years, John laid out in Earth-Science Reviews how sediments are recycled between source and sink during eustatic cycles[48]. This work will undoubtedly serve as the seminal text for future students of sedimentology and lays the framework for understanding how human-induced climate change may influence our coastlines.

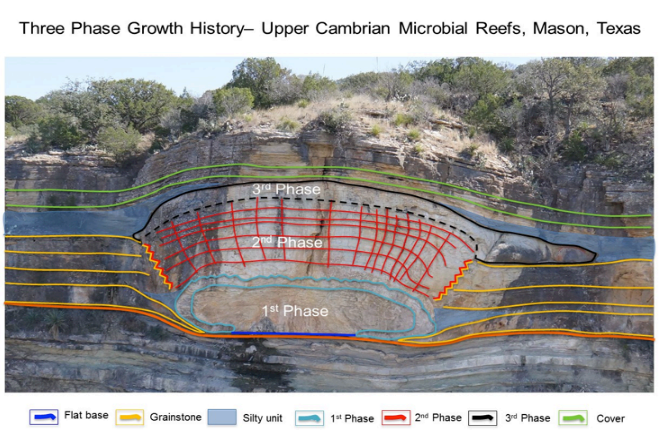
Anna Ruth Halberstadt (L), Lindsay Prothro, Lauren Simkins, and Brian Demet (R) during an expedition to the Ross Sea off of Antarctica. Right panel shows high resolution seafloor bathymetric map, which reveals numerous morphological structures left behind by the Antarctic ice sheet[43].

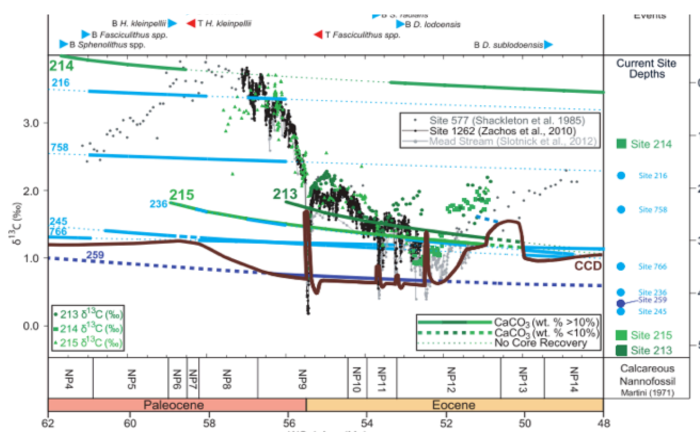


Climates and environments of the past

It would seem that Texans are always trying to get away from the heat, but Gerald "Jerry" Dickens seems to always find himself in hot water. Jerry continues to return to Paleocene-Eocene times, which were characterized by several climatic excursions to hothouse conditions, specifically the Paleocene-Eocene Thermal Maximum (PETM). Ben Slotnick and Jerry reconstructed a high resolution carbon isotopic and lithologic record of Early Eocene marine sediments in New Zealand to show that hyperthermals, identified by extreme carbon isotopic excursions, coincided with massive terrigenous influx, which they attribute to increased seasonality during these climatic excursions[49]. Ben and Jerry also reconstructed the depth of the carbonate compensation depth (CCD) during the early Paleogene from sedimentary cores on Ninetyeast Ridge in the Indian ocean; although on short timescales, increases in atmospheric CO_2 concentrations acidify the ocean and cause the CCD to shoal, increases in carbon fluxing on long timescales causes the CCD to deepen[50]. This study represents a potential approach for reconstructing long term inputs and outputs of carbon into the Earth's exogenic system and dovetails nicely with the work that Rajdeep Dasgupta's and Cin-Ty Lee's groups are doing on quantifying long term volatile fluxing between the deep and surface Earth.

Going back in time to the Cambrian, we find Andre Droxler with his graduate students Pankaj Khanna, Heath Hopson, and Jacob Proctor scrambling over ancient carbonate bioherms (stromatolites), photomapping them with the aid of drones at an unprecedented level of resolution. These bioherms are exposed on a central Texas ranch and represent one of few ancient bioherms in which one has a three-dimensional perspective. We hope to see these results published soon: preliminary data are already adding to our understanding of the 3-D architecture of algal colonies.





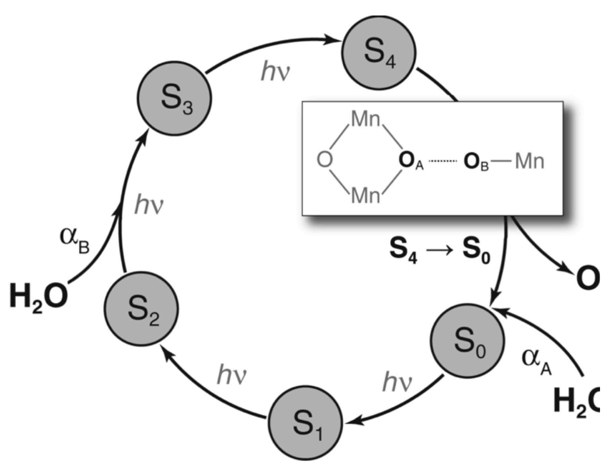
Left: 2D cross section of Upper Cambrian Microbial Reef, Pointpeak Member of Wilberns Formation, Zesch Cliff, along the Llano River, Mason, Texas (Pankaj Khanna, Andre Droxler). Right: Constraints on the depth of the carbonate compensation depth (CCD) in the early Eocene (brown line) based on different sites around the world[50].

Dynamics of the ocean, atmosphere and biosphere

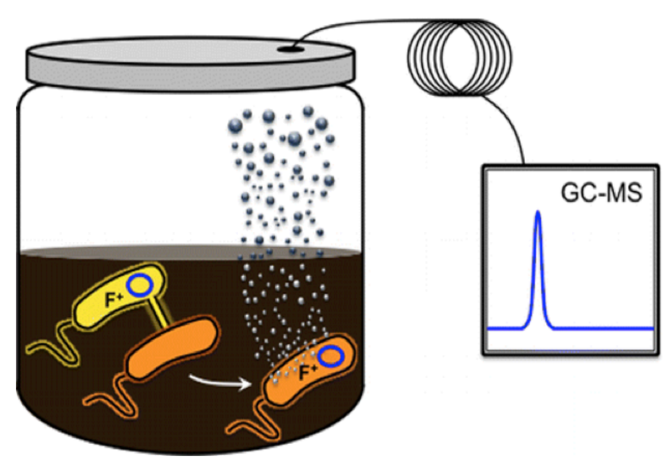
Our most recent faculty, Laurence Yeung, arrived in 2014 and has been rapidly building state of the art facilities for high resolution stable isotope ratio mass spectrometry. We now have three gas source isotope ratio mass spectrometers on the third floor. Laurence is one of the leaders in clumped isotope geochemistry, a relatively new application which takes advantage of the preference for rare isotopes to clump together in a molecule, resulting in slight deviations from random or stochastic combination of isotopes. These deviations have only recently been explored. Clumping is now being used to extract paleo-temperatures without the need of thermometry pairs or assumptions about the composition of reservoirs, such as the ocean through time. But even in this rapidly evolving field of clumped isotopes, Laurence is on the forefront. Last year, in a paper published in Science magazine, Laurence and Jeanine Ash showed using terrarium experiments that biological cycling of oxygen drives clumping away from equilibrium, thus not all clumping signatures reflect temperature[51]. This work significantly expands the applications of clumped isotopes to environmental problems, and may provide a unique way to unambiguously detect and quantify biological processes back in time or on other planets. As a follow-up to this paper, Laurence has laid out the basic principles and theory of interpreting clumped isotopes in Geochimica Cosmochimica Acta, which will likely serve as the official text for future students[52]. Laurence is currently measuring in his lab the clumped isotopic signatures in gases trapped in Greenland ice cores to unravel atmospheric dynamics back in time.

Biochar and biosensors

Our department is also making headway in truly interdisciplinary studies. Carrie Masiello continues her investigations on the prospects and limitations of using biochar as a soil amendment and vehicle for long term carbon sequestration. Her range of applications, building on numerous cross-departmental collaborations, was wide. These include studies of the hydrologic properties of biochar-amended soils with graduate student Zuolin Liu, Brandon Dugan and Helge Gonnermann[53,54], dynamics of nutrient transport in biochar-amended soils with Kyriacos Zygourakis in the Chemical Engineering department[55], carbon and nitrogen isotopic constraints on the nature of pyrolysis with former graduate student Morgan Gallagher and post-doctorate Bill Hockaday[56] and biochar effects on micronutrient availability[57]. With Bill Hockaday, Carrie also outlined how changes in CO_2 availability influenced the oxidative ratio of biological productivity, an important quantity necessary for quantifying global carbon cycle models[58].



O_2 formation in one part of the photosynthetic process. A five-step cycle is involved in splitting water to make O_2: $2H_2O + 4hv \rightarrow O_2 + 4H^+ + 4e^-$. Transitions between intermediate oxidation states in the cycle (S_0 to S_4) occur upon absorption of visible light. Clumping and anti-clumping of rare isotopes were shown by Yeung to be sensitive to these biological processes[51].



Dynamic gene expression in a microbial population in soil can be expressed by the production of methyl halides gases. Gas reporting of gene expression will enable dynamic studies of natural and engineered microbes within many hard-to-image environmental matrices (soils, sediments, sludge, and biomass)[59].

This past year was also a windfall for Carrie. In collaboration with George Bennett and Jonathan Silberg from the department of Biochemistry, Carrie was awarded a 1 million dollar grant from the Keck Foundation to develop biosensors as a tool for interrogating microbial processes in soils and other natural environments. Most approaches used to detect microbial activity are based on visual signatures of gene expression, which are difficult to see in soils. Carrie and her collaborators are bioengineering microbes to release gases under specific conditions, which they hope to be able to detect in soils in real time. Graduate student Hsiao-Ying Cheng led their first paper, a proof-of-concept study published in Environmental Science and Technology[59]. Stay tuned to next year for more results of this innovative study.

Exploration and environmental geophysics

Colin Zelt continues to develop methodologies for interpreting seismic data. With graduate student Jianxiong Chen, they are developing frequency-dependent traveltime tomography with full waveform inversion for application to environmental problems[60,61]. William Symes, joint with the Computational and Applied Math department, worked with graduate student Jie Hou on improving methods of least square migration of seismic data[62].

Undergraduates lead in research and graduate students and post-docs move on to the real world

Our senior undergraduate honors thesis program began last year. Our first seniors to graduate under this program were Maya Stokes (Synsedimentary deformation in prodelta sedimentary deposits), Michelle Muth (Compositional controls on CO_2 solublity in rhyolitic melts) and Rachel Marzen (Modeling effects of cohesion on interactions between erosion and exhumation in bivergent orogens). Our 2016 honors graduates were Adeene Denton (Ice deformation on Enceladus), Larisa LaMere (Effects of goethite on biochar porosity), Emily Paine (Origin of orbicular granitoids), and Elli Ronay (Characterization of volcanic ash in the Eagle Ford formation). Maya, Michelle, and Rachel are in PhD programs at MIT, University of Oregon, and Columbia, respectively. Adeene and Elli will start their PhDs this fall at Brown and Vanderbilt Universities.

Emily is working for the National Institute of Standards and Larisa is continuing at Rice as a research assistant and co-editor of this journal, and beginning full time work with a Houston non-profit this fall! We are proud to also announce that both Maya Stokes and Elli Ronay are recipients of the much coveted National Science Foundation Graduate Research Fellowship. Finally, we are proud of our recent graduates and post-doctoral fellows. Jianxiong Chen is now at Anadarko, Emily Chin went to Brown University as a post-doctorate and is starting an assistant professorship at the Scripps Oceanographic Institute at the University of California in San Diego, Sarah Dean is at Shell, Monica Erdman is working at Hess, Megan Duncan is a post-doctorate at the Geophysical Lab at the Carnegie Institution of Washington, Rodrigo Fernandez is a research associate at the University of Texas Institute of Geophysics, Brandon Harper is at Conoco-Phillips, Ananya Mallik is a post-doctorate at the Institute of Geosciences in Bayreuth. In Germany, Jennifer Masy is at Osprey Energy, Becky Minzoni is an Assistant Professor at the University of Alabama, Ben Slotnick is at BP, Sally Thurner is at Noble Energy, and Matt Weller became a post-doctorate at the Lunar and Planetary Institute in Houston and is starting this fall as a post-doctorate at UT Austin. Post-doctoral fellows Thomas Giachetti is now an assistant professor at the University of Oregon, Wenrong Cao is starting as an assistant professor at the University of Nevada, Reno, Eric Kiser is starting as an assistant professor at the University of Arizona, Tucson, and Yuan Li is starting as an assistant professor at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. Congratulations to all!

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A Conversation with Adrian Lenardic

Planetary thermal evolution, fluid dynamics, mantle convection, skateboarding.

Interview by Larisa LaMere.

At the skate park. Photo by Adrian Lenardic.

Dr. Lenardic, we at Rice know you as a highly accomplished geodynamicist and planetary geophysicist. But if somebody from outside the academic realm asked you at a party, "what do you do?" how would you answer?

That happens quite a bit. I usually start by saying I work at Rice and then wait to see what happens. The range things that people have said to fill in the blank "Oh…Rice, so you _______" has been interesting. For the longest time one of our friends, from a Vespa group that my wife and I are a part of, assumed that I worked at Rice Epicurean (a grocery market). If people follow up, I tell them I teach and do research related to the evolution of our planet and how our planet compares to other rocky planets in our solar system. If they are curious beyond that I give some examples such as "Most recently I have become interested in how volcanic and tectonic activity interacts with the climate of our planet over long time scales and how that feeds into the conditions that have allowed for life on our planet over geologic time."

"Most recently I have become interested in how volcanic and tectonic activity interacts with the climate of our planet over long time scales and how that feeds into the conditions that have allowed for life on our planet over geologic time."

You recently had two groundbreaking papers published in Nature and Astrobiology about Earth's climate evolution and new potential for life on other planets. What was your most surprising finding from these studies?

Related to surprise, I can give you a quote from a paper we have in review: "… an enduring insight we as people have gained from our explorations of terrestrial planets, and satellites, thus far in our history of such exploration: Each has provided us with surprises and all, to variable degrees, appear to have evolved differently." Sometimes there is a perception that science, what with the laws of nature it has discovered and the rules it lives by, is a boring thing because "laws" tend to imply limited possibilities in terms of what can exist and in terms of what one can discover and, given that, there can be no true surprises. In my experience that is incorrect. Laws of nature mixed with evolutionary/historical contingencies allow for a range of diversity – a diversity we can study so as to gain some understanding (literally to stand below and see the structure). That diversity, within the laws of nature, when I step back a bit from the desk or the computer, still surprises me to no end.

Good mentors have the ability to influence the course of our lives. Who was your primary mentor while you were a student?

In graduate school it was my advisor William Kaula (Bill). Bill was one of the only professors at a major university who did not have a PhD – developing a new field will do that for you. It's rare. What it meant for Bill, in my recollection, is that he could break out of conventional lines of thought. There was a joke amongst graduate students that you had to learn Kaula-ese (his own unique way of thinking and expressing thoughts) before you could even start to appreciate what he could teach you - not everyone learned his language and I have always felt lucky I did. He had little time for nonsense (a word he enjoyed), which was a term that went beyond just right and wrong answers to science problems but also applied to not getting bogged down in irrelevant formalities and/or imposed procedures that made no sense and/or feeling compelled to pursue problems simply because they could get you grants and/or publications. His take was to tackle problems that interested you at your core and (I recall him saying this to me directly) problems you actually had the skills for. In other words, he meant that I really needed to know myself and be myself before I could really contribute to science.

Bill also had a way of keeping the pressure off and reminding you that research, even if difficult at times, was supposed to be enjoyable. My family is first generation immigrants from Croatia, who started an auto body/mechanics shop when they came to the U.S. There's a Croatian saying that goes, "if you put the child on his or her feet and they are happy, you have done your job well." Being happy in what you are doing is primary and the job title itself is secondary – whatever you do is seen as valuable and there is no sort of rank ordering. My family is proud of me, of course, but that has nothing to do with any sort of job title. That has kept me grounded.

Adrian Lenardic is a professor of geophysics in the Earth Science Department.

I've heard that you skateboard. What's it like to be a part of the Houston skating community? Have you made future scientists out of any younger skaters yet?

Being a skater is integral to my sense of identity within Houston. That may sound all hoity-toity but it's the most honest answer I can give you short of taking you out skating with me for a year or two so you can experience it for yourself. I do it because it is what I love to do. I have talked to plenty of kids in the skate parks and they all know I'm a scientist. I don't know about making science-disciples, but they do but they do like to ask me questions about the earth or other planets or about the physics of skating and I'm always happy to tell them what I know. The interest is genuine and the questions are great. I don't know the answer to a lot of them so we talk about them and see if we can work out an answer or maybe an experiment we can do to address the question – to me, that's education at its best (and by that I also mean education for me).

Is there anything else you think we should know about you? Favorite equation?

Favorite equation? I like that. I recently ran across a book called Formulas for Now (edited by Hans Ulrich Obrist). The book asks a range of Scientists and Artists to present "equations". The first contribution that got stuck in my head is from Gregory Chaitin (a mathematician) and is related to the halting problem (in short, the probability that a computer program will stop versus continuing to calculate – you can write an equation for the probability but it turns out the precise numerical value of the probability is incomputable and irreducibly complex). He gives the equation and then provides an interpretation: "The probability can be interpreted pessimistically, as indicating that there are limits to human knowledge. The optimistic interpretation, which I prefer, is that the probability shows that one cannot do mathematics mechanically and that intuition and creativity are essential". The other is from Gino Serge (a physicist and author of some great popular science books).

Art = Beauty

Science = Beauty

Art/Sci* is the limit

***indeed the Sci's the limit**

by Gino Segre

Climate affected by extra source of volcanic CO_2 degassing

by Laura Carter

In today's science news, "climate change" and "greenhouse effect" are common words because, human fossil fuel consumption contributes extreme amounts of carbon dioxide—a green house gas, CO_2— to the atmosphere since 1850. This has sparked many scientific investigations into long term (on a million year time scale) climate variation as the result of global CO_2 cycling processes. Recent work suggests that further back in time, e.g. the Cretaceous period (~65 million years ago), normal processes in nature, such as volcanic activity, could have been a more important contributor of CO_2 to the atmosphere than it is today, due to changes in the location of volcanism, magma supply, and number of active volcanoes.

During the Cretaceous period when sea level was higher, carbon was locked in carbonate rocks deposited in shallow marine settings within the continents, such as the Western Interior Seaway that spanned from Canada through Texas. After sea level receded again, most of the coastline of North America (the Sierra Nevada volcanic arc), like other tectonic plate margins around the world, experienced active volcanism as oceanic crust subducted beneath continental crust and melted. As magma rose from the mantle through ≤40 kilometers of crust, it interacted with the surrounding crustal rocks before crystallizing as granitic batholiths that are now exposed within the Sierra Nevada Mountains, or erupting to the surface as lava[1, 2].

When magma intrudes into rocks containing carbonate, interaction with magma can break the rock down, triggering CO_2 gas release in two different ways: 1) assimilation, in which the carbonate is broken down and consumed by the molten liquid[3]; and 2) skarnification (see Figure 1), in which elements dissolved in the hot aqueous fluids that leach from the magma body alter the surrounding mineralogy and produce ores like copper[4]. Both processes are expected to release carbon dioxide from the rock (see Reaction 1 and 2 respectively in Figure 1). As a gas, the CO_2 can escape the magma at the volcanic vent either passively or during an eruption.

Skarns exposed by erosion are well-documented by ore geologists, who investigate their physical and geochemical properties by collecting rock samples from outcrops. In contrast, volcanologists and petrologists must use laboratory modeling techniques and measurable observations to understand assimilation processes. For instance, assimilation causes high CO_2 outputs at volcanoes, carbonate ejecta in the lava, and geochemical signatures that show mantle-and-crust mixing, such as at Mt. Etna and Vesuvius in Italy, Popocatepetl in Mexico, and Mt. Merapi in Indonesia 3. Since these volcanoes recently erupted proximal to dense population areas, their gas fluxes are closely monitored especially because extra CO_2 has been linked to increased explosivity during eruption--dangerous for nearby communities.

Since magma-crust interaction happens at significant depth, the best way to investigate these processes is via laboratory experiments. One of these, a pressure cooker of sorts, is a piston cylinder apparatus, which uses hydraulic presses to simulate variable depths in the crust (up to 100,000 times atmospheric pressure, ~35 km deep), while electricity heats the system to magmatic temperatures (up to 1200 °C). The magma is given time to interact with carbonate (up to a few days), then they are flash cooled to freeze the melt into a glass for analysis[3].

Experiments have determined that the extent of melt availability determines the amount of carbonate that can be dissolved, meaning hotter magma chambers are able to release more carbon and consume as much carbonate as half of the mass of magma[3]. By weight, half of the consumed carbonate is then converted to CO_2, while the other chemicals remain in the magma (Reaction 1, Figure 1). Additionally, experiments with different types of magma indicate that magmas near the surface have significantly cooled and crystallized minerals, changes the composition of the residual melt (dacite). Dacite cannot ingest as much carbonate as the younger, hotter magmas (basalt, andesite; see Figure 1)[5]. This means that as the magma ascends to the surface it releases a lot of extra CO_2 early on, but slows over time.

Near the Earth's surface, water cannot dissolve as easily in magmas, meaning that any H_2O transported in the magma from the subducted oceanic plate will leach into the surrounding carbonate rock (see "skarn aureole" in schematic). At this point, reaction 2 occurs, which trades the carbonate mineral for unique skarn minerals and releases CO_2[4] (Reaction 2, Figure 1). It is unknown how far the water can migrate away from the magma (Centimeters? Kilometers?), making it difficult to quantify how much carbonate is broken down, but it seems probable that skarnification releases more CO_2 than assimilation near the end of the magma's path.

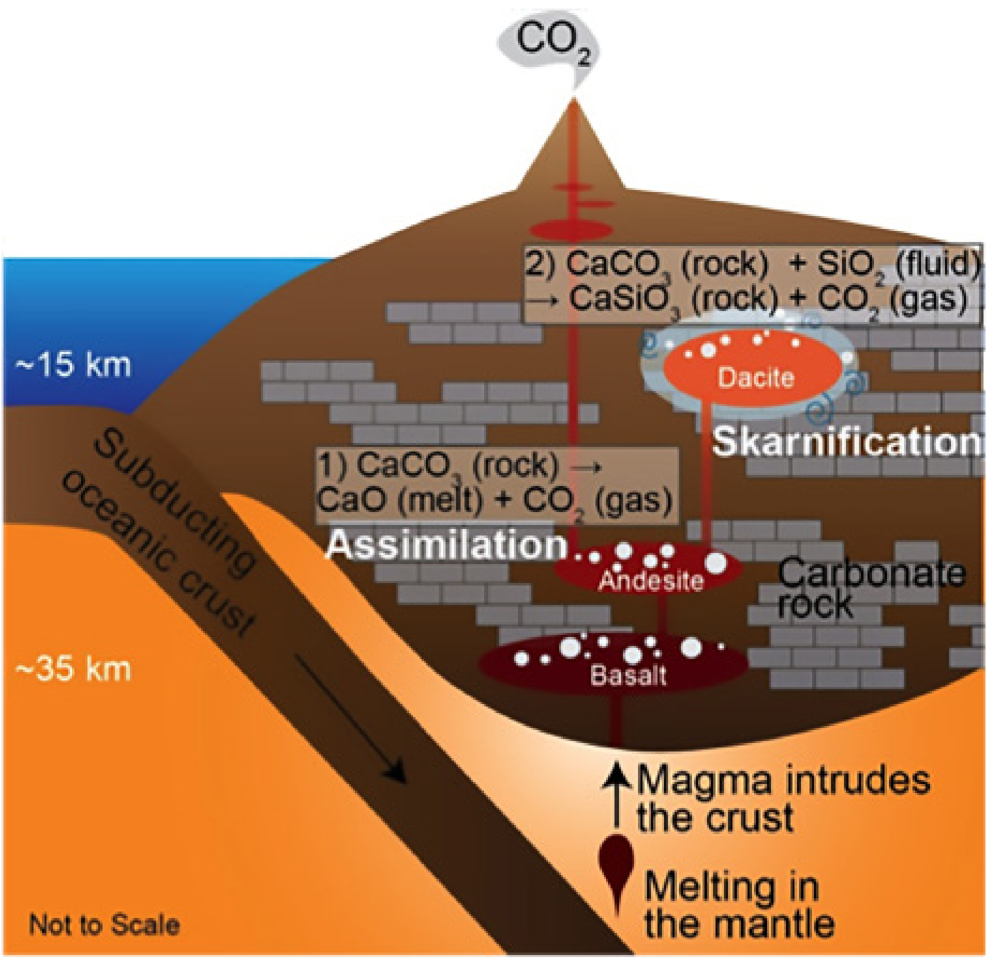

Figure 1. Assimilation and skarnification processes in volcanism at convergent plate margins.

Reaction 1: CaCO3 (rock) → CaO (melt) + CO2 (gas).

Reaction 2: CaCO3 (rock) + SiO2 (fluid) → CaSiO3 (rock) + CO2 (gas)

Due to a higher number of volcanoes (particularly those sitting atop carbonate rocks, in the Cretaceous period), the atmosphere could have received as much as 10-100 times the present-day volcanic CO_2 output[3,5,7]. Comparing the amount of CO_2 produced in experiments with measured present-day degassing rates at particular volcanoes, however, suggests that only a portion of the magma chamber interacts with surrounding carbonate (<50% at Merapi, Etna, Vesuvius and Popocatepetl)[5]. If this was true in the Cretaceous period, too, then volcanoes could have degassed more than observed in modern times.

Breakdown of carbonate in any of these forms enhances the dangers of the volcanic system[9]. First, the rock underlying the volcano is now weak and unstable, making landslides more likely, like the one that may have kicked off the 1980 eruption at Mt. St. Helens. Second, if any barriers (such as crystals or viscous magma) prevent gas escape, the pressure can build up and either cause earthquakes and/or produce more violent volcanic eruptions (such as when the cap is taken off a shaken soda bottle). This is dangerous and destructive to nearby communities, like those affected by the 2010 Merapi eruption (see Figure 2).

Another important consequence of assimilation and/or skarnification is that by contributing potentially significant amounts of carbon dioxide—a greenhouse gas—to the atmosphere, these processes may play a role in climate change. Today, industrial inputs greatly exceed volcanic emissions, and are often linked to the current short-term changing, warmer climate. In the deep geologic record, experiments suggest that carbonate-magma interaction within the crust throughout Earth's billion year history could have spiked atmospheric CO_2 concentrations and led to warming before human fossil fuel interference, but on much longer timescales.

Figure 2: A house destroyed by the 2010 Merapi eruption. Photo Credit BAYISMOYO/AFP/Getty7 Images.

Laura Carter is a fourth year PhD candidate in experimental petrology, advised by Dr. Rajdeep Dasgupta

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Eventually I reached a point where I needed to decide between returning to Germany to continue my apprenticeship as a cabinetmaker, committing to a growing business of restoring pianos, or becoming a full-time student at the University of Montana. By a hair's breadth, I chose to continue my studies.

Helge Gonnermann and the path to professorship

Helge Gonnermann is a professor of geophysics in the Earth Science Department

It is great to be a professor at Rice, but my path to get here wasn't linear. I grew up in a small farming town in Germany, thinking I was going to be a cabinetmaker, like my grandfather. However, I had a fascination with America – probably from watching too many Westerns and from listening to American music. After my civil service and a year as a woodworking apprentice, I moved to Montana, where I met a wide range of interesting people who impacted my life. After spending a couple of summers and snowy winters as a ranch hand while living in a cabin on the Flathead Reservation, I moved to Missoula, where I enrolled in a couple of science classes at the University of Montana. As a part-time student, I got by as a dishwasher and short cook before working for a retired music professor who owned a piano store and taught me how to restore old pianos.

My curiosity in science was spawned by a biology high-school teacher who was passionate about science and teaching. Not surprisingly, I thought that I was interested in the dynamics of ecosystems so my initial course interests were in biology. After a botany course I wanted to take a soil science course but lacked the prerequisites. Instead I enrolled in an introductory Geology course, thinking that there was an obvious connection between a bunch of dead rocks and soil. What I had not bargained for were plate tectonics and orogeny. As I learned that the mountains that I had been living in had a rather illustrious and ongoing history, I came to realize that Earth is the ultimate dynamic system and that Geology wasn't just the study of a bunch of rocks that turn into soil.

Eventually I reached a point where I needed to decide between returning to Germany to continue my apprenticeship as a cabinetmaker, committing to a growing business of restoring pianos, or becoming a full-time student at the University of Montana. By a hair's breadth I chose to continue my studies.

Life is often affected by unpredictable events. One year there was a huge snowstorm during which I ventured outside to enjoy the eerie quietness. Walking down the street through the thick snow I encountered this guy lying on a piece of cardboard underneath a Jeep Cherokee, holding a blowtorch to his oil pan. Being the only two people out and about, together with his rather unconventional way to get his car started, prompted me to ask if he wanted some help. From below the Jeep came the grey bearded face of a man who replied, "Sure you can!"

...I ENCOUNTERED THIS GUY LYING ON A PIECE OF CARDBOARD UNDERNEATH A JEEP CHEROKEE

After quite some time we got his car started and the man, Don Winston, asked if I wanted to drive up into the mountains with him, where he had a home and a bunch of pack llamas, all named after the Carter Family of American folk music fame, that he needed to tend to. I took him up on his offer.

Helge Gonnermann. Photo by Jeffrey Piccirillo.

With the storm approaching Don had moved the llamas into a barn, but his two males needed to be kept separate. Thus A.P. Carter was in the basement of Don's house. Because Don had not consulted with his wife about this arrangement, he was rather eager to do some damage control. So off we went into the Mountains, making tracks in several feet of fresh snow, this was the first of many adventurous trips with Don. It turns out that Don was a Geology professor and as a UM Geology undergrad I would eventually be taking inspirational field trips with him, plus I would end up spending a couple of summers as his field assistant.

As a Geology major I was fascinated by tectonics, but I also grew somewhat leery of the vagaries of geologic interpretation. Through some geophysics and hydrogeology courses I found myself drawn toward the seeming comfort of numbers. This led me to the University of Arizona, where I got a Master's degree in geophysics. I subsequently worked as a hydrogeologist in San Francisco, in part because I wanted to have a beneficial societal impact in what I was doing. It was during this time that I met my wife, Elizabeth.

As a hydrogeologist I was fortunate to work on interesting projects and with great colleagues, but there was still much that I wanted to learn. I eventually applied to several PhD programs, with the goal to learn more about fluid dynamics. This is how I ended up as student with Mark Richards at UC Berkeley, studying mantle convection. During the first couple of years I worked closely with a postdoc named Mark Jellinek, who became a good friend and mentor. After Michael Manga joined the Berkeley faculty I began working with him on the fluid mechanics of volcanoes and he became my thesis advisor.

Pursuing things that I found interesting and engaging is what eventually led me to Rice. Among the things I enjoy most about Rice's Earth Science department are its collegiality, the intellectual stimulation provided by faculty, students and postdocs, and of course the freedom to pursue my research and teaching interests. That's what this environment provides, and it is a privilege to be part of it.

Among the things I enjoy most about Rice's Earth Science department are its collegiality, the intellectual stimulation provided by faculty, students and postdocs, and of course the freedom to pursue my research and teaching interests.

Interview by Larisa LaMere

Gonnermann and students in NM. Photo by Jeffrey Piccirillo.

Department Travels... 2015-2016

The Rice Earth Science department is frequently on the move, exploring both familiar and foreign locations, seeking to uncover natural mysteries hidden all across the globe.

Destination Lake Baikal: in search of the “ideal” modern shelf-edge delta

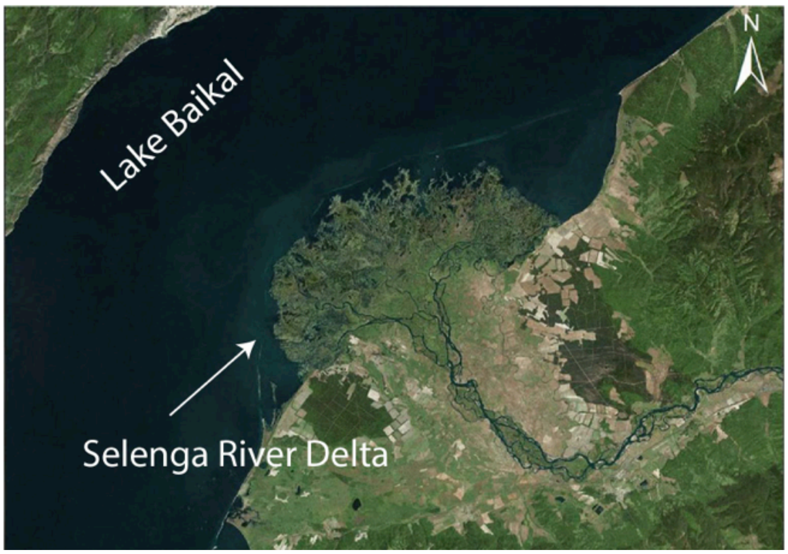
by Tian Dong and Jeffrey Nittrouer

After a 2-day long journey that started at Rice University and ended in the heart of Siberia, Professor Jeff Nittrouer and his graduate student Tian Dong finally reach their destination: a camp on the Selenga delta located along the southeastern shore of Lake Baikal; this will be home for the next month. Behind them lies the late July summer heat in humid Houston. Before them lies a great mission: to locate and survey the ideal modern shelf-edge delta, specifically the Selenge River delta, which flows into the world’s largest and deepest freshwater lake.

Formed by a half-graben styled intracontinental rift that initiated 25 million years ago, Lake Baikal – the oldest lake in the world – extends over 600 km in length with an average width of 60 km and possesses a maximum depth in excess of 1.6 km. These dimensions render Lake Baikal the largest volume of unfrozen surface freshwater in the world, and the Selenga River is its biggest contributor of sediment and water. Covering ~ 560 km^2, the modern Selenga River delta is one of the largest freshwater deltas in the world.

Other than its impressive size, what else makes this system so special to make it worth crossing two continents and the Pacific Ocean to investigate scientifically? It turns out that the Selenga River delta is positioned along the deep-water margin of Lake Baikal, qualifying it as a rare modern shelf-edge delta system. Flooding of continental shelves all around the world as a result of sea-level highstand has pushed most if not all of modern marine deltas landward, sometimes several hundred kilometers from the continental slope. Therefore, due to its basin margin position, the Selenga delta represents an ideal system to study sediment dispersal processes that transfer mass directly from the delta topset to deep-water depositional environments.

The objective of this particular Russian-American collaborative field expedition is to investigate the hydrological and sediment transport dynamics of the bifurcating channel network on the Selenga delta's topset. Field work includes sampling sediment from the channel bed and bankline and surveying channel bathymetry from major and minor distributary channels. In terms of the results of this campaign, field data indicated a downstream fining of sediment, ranging from predominantly gravel and sand near the delta apex, to silt and very fine sand at the delta-lake interface; in fact, median grain size drops by three orders of magnitude over a relatively short topset distance (~ 35 km). Subsequent work back at Rice University includes developing an analytical framework to explain the downstream fining and elimination of gravel from the delta dispersal system. The analyses of hydrological data suggest that a significant spatial decline in boundary shear stress arises as water is partitioned within the bifurcating channel network.



Satellite image of the Selenga River delta and Lake Baikal. Covering 560 km^2, the Selenga delta is one of the largest freshwater delta in the world.

In addition to the scientific work, this international collaboration has provided incredible cultural experiences by way of interacting with Russian scientists, tasting local cuisine, and exploring the beautiful landscape of rural Siberia. The local people, Buryatians, are descendants of the Mongols and have called the shores of Lake Baikal home for many centuries. Through fishing and farming, the Buryat communities have thrived on the natural resources gifted from Lake Baikal. To the indigenous people, the smell smoked Omul (fish) soup, sound of traditional Mongol music and dance, and love of horses are all traditions that are as integral as the Selenga River. For earth scientists, it is critical to continue studies about the natural development and processes that build this beautiful deltaic system, with an eye toward understanding the broader geological significance of the Selenga system.

The Rice Sedimentology Group aims to produce future collaborative scientific expeditions to inform about the dynamics of the Selenga delta and Baikal, and this research will be used to advance geoscience and foster effective policymaking to preserve the Selenga system for its people. In fact, the next trip is already being planned: a winter expedition intended to shoot ground penetrating radar (GPR) in order to reveal the internal stratigraphic architecture of the delta. Why winter? Because the delta and lake are frozen solid, thus sampling via a snow mobile-drawn GPR unit will be extremely effective for covering the entire delta, from topset to foreset. Only this time, Professor Nittrouer and graduate student Dong will dream of the warmer weather back home in Houston.

The native people to Lake Baikal, Buryatians, wearing traditional dresses and singing to welcome the expedition team. Photo by Tian Dong.

TURKEY

Right: Geological Map of Istanbul Zone, Turkey. Photo by Jeffrey Piccirillo.

Left: Pankaj Khanna and Nur Koyuncu examining the Late Cretaceous serpentinite during the Department Type Locale Field Trip 2015, in Turkey. Photo by Jeffrey Piccirillo.

Ecolgite with garnet from the Tiburon Peninsula, CA. Photo by Cin Ty Lee

Earth Chemistry and Materials (ESCI 322) field trip to northern California. Photo by Hehe Jiang.

CALIFORNIA

WASHINGTON

Layered flow deposits on the rim of the Mazama caldera.
Photo by Thomas Giachetti.

Physical Volcanology (ESCI 429) field trip to Southern Washington. Photo by Thomas Giachetti.

IRELAND

Advanced Topics in Basin Sedimentology and Stratigraphy (ESCI 546). Photo by Tian Dong.

Large fold within the Ross Formation.
Photo by Tian Dong.

CENTRAL TEXAS

One billion year old serpentinite, as seen on an undergraduate-organized field trip. Photo by Cin Ty Lee.

MORE ADVENTURES AWAIT IN 2017!

Alumni profiles: Martin Schuepbach

interview by Larisa LaMere

Martin Schuepbach obtained his PhD at Rice in 1974. His thesis was entitled "Comparison of Slope and Basinal Sediment Between a Marginal Cratonic Basin and a Marginal Geosynclinal Basin," and he did his research with professors James Lee Wilson, Clark Burchfiel and John Warme.

He went on to work for ExxonMobil and Maxus Energy before starting his own energy exploration company, Schuepbach Energy, Inc. in 2007.

What Rice taught me:

As a Masters student in Switzerland, professors were like stern parents: not to be questioned and impossible to challenge. You were to learn according to what they taught you: classic structural geology ideas that hadn't been revised in years.

Coming to Rice for my doctorate gave me a new taste of structural geology. In classes, part of my grade depended on discussion participation. I was encouraged to speak up and think independently. I interacted with professors who were open to learning new things. And I constantly had my geology paradigms challenged, especially by other students. It was a powerful experience.

The rigorous research environment at Rice made me a better scientist, and lent to my deep conviction that it is important to always question, challenge, and think independently about information given to you. This conviction has followed my professional life after getting my Ph.D.

Advice for aspiring geology entrepreneurs:

1. **Think critically:** find the answer for all the questions that you have about a project before you start drilling -- or investing. Know what you are getting yourself into.

2. **Think technically:** do your own "field work." Don't trust what other people have told you about the area you're going into. In my experience important things often get overlooked or forgotten, and those things can be the base of your growth.

3. **Stay current:** always be up to date with equipment and technology: innovation and competitiveness are where new methods and products are being developed.

4. **Listen:** it is always much better to listen to people than to talk when you are meeting with them. When you begin to interface with your customers or partners, listening is key to you getting a better understanding of what need your product can fill or what problem it can solve, and the setting (political, economic, geologic) under which you're operating.

And most important:

Do what you love to do. I am not somebody who enjoys working in the office setting. I wanted more freedom in my life. Always remember that you have the freedom to choose how you spend your working life.

Evaluating the long-term sustainability of deltas

by Andrew Moodie

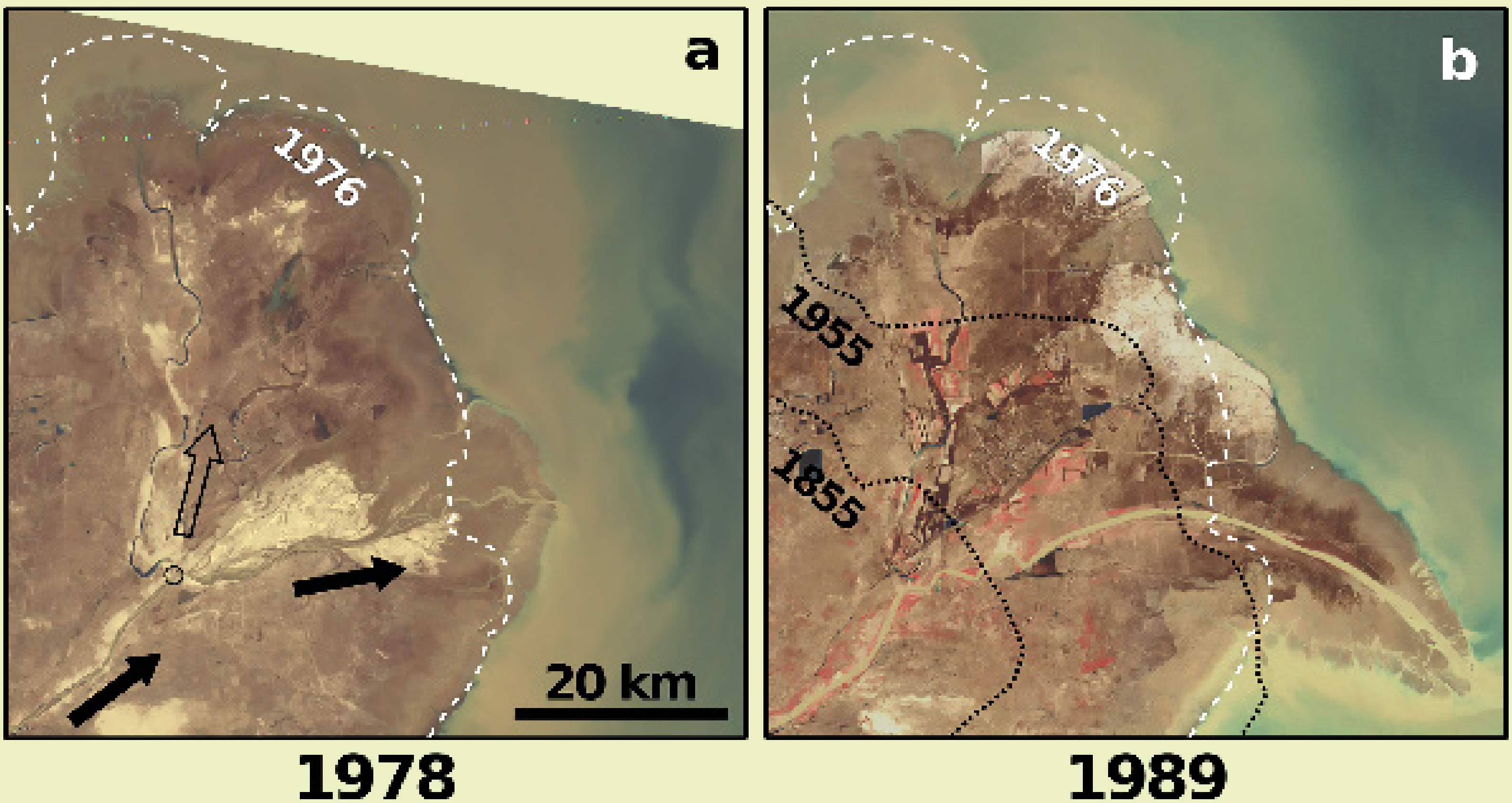


Figure 1: (a) satellite composite of the Yellow River delta, China in 1978, two years after a deltaic avulsion in 1976 occurred ~60 km upstream of the old river mouth (circle) which changed the channel course from the north (open arrow) to the east (solid arrow). The shift in the 1976 coastline demarcates the over 250 km^2 of land built as a new channel lobe in just two years and the significant marine reworking of the old channel lobe. (b) satellite composite from 1989 over the same area overlain with a historical record of mapped coastlines demonstrating the net delta growth over many avulsion cycles (black dotted lines) [van Gelder et al., 1994]. Satelllite data courtesy USGS.

Deltaic environments are critical for societal well-being because these landscapes possess an abundance of natural resources that promote human welfare, such as fertile soil and shipping channels. However, the sustainability of deltas is far from certain, due to a multitude of natural and anthropogenic factors. The management of important domestic deltas for the last several centuries, for example the Mississippi River delta, has led to a retreating delta coastline and channel shoaling, threatening the port of New Orleans with exposure to coastal storms and reduced channel navigability.

Fortunately, emerging research indicates the feasibility of reversing land-loss through controlled diversion of river water and sediment[1]. This research seeks to build on this work and evaluate the Yellow River fluvial-deltaic system, China, to identify best practices for promoting long-term deltaic sustainability in the face of anthropogenic influence that threatens the sustainability of the delta. Due to an extremely high sediment load, variable water discharge, and confinement within man-made levees, the Yellow River channel is prone to rapid sediment deposition to the bed and aggradation that render this system highly unstable over seasonal to decadal timescales[2, 3]. Interestingly, the rapid system dynamics provide unparalleled opportunities to research delta development mechanisms that normally occur over millennia, and so the Yellow River and its delta are ideal locations to pursue process-based studies linking physical properties of fluid flow and sediment transport to understand the long-term development of deltas.

Deltas represent the dynamic interplay between fluvial sedimentation, subsidence, and sea level change. Where sediment supply is high the delta will locally grow and move the coastline forward as a delta lobe; conversely, where sedimentation is low, the coastline lacks nourishing sediment and experiences local retreat (Fig. 1). Similarly, land subsidence and sea-level rise force coastline retreat across the entire low-relief delta simultaneously. Through overbank flooding and avulsion, the process by which the channel catastrophically floods overbank and carves a new course to the sea via an alternative, gravitationally advantageous path, natural deltas distribute necessary sediment to the entire coastline so as to maintain a state of morphodynamic balance[4]. However, the unanticipated civil disruption associated with flooding and channel relocation is naturally at odds with the societal desire for landscape stability for continued economic use. Therefore, on highly developed deltas sediment delivery to the coast is frequently reduced and is outpaced by land subsidence and sea-level rise, beginning a pattern of deltaic land loss. A commonly cited example of this is the Mississippi River delta, where high channel levees and channel-course engineering have cut off sediment supply to the low-relief bayous of the Louisiana coast, causing a land loss rate of about 44 km^2 per year[5].

> “Societal development and natural deltaic processes will continue to be at odds to one another, but recent research out of the process-based sedimentology community supports the notion that coastline stability and a prosperous society are not mutually exclusive...”

For millennia, Chinese governments have implemented significant engineering efforts to prevent channel avulsions and catastrophic flooding along the lower Yellow River, in accordance with promoting rapid anthropogenic development of the delta for aquaculture and hydrocarbon extraction[6]. Most recently, the Water and Sediment Discharge Regulation project (WSDR) was established to release artificial, sediment-depleted flood waves from a network of reservoirs and dams ending ~800 km upstream of the delta. The intention of the project is to use the higher transport capacity of the flooding river to reverse in-channel sediment aggradation and stave off damaging avulsion and flooding that threaten the society developed on the delta. Additionally, avulsions are engineered to shorten the distance to the sea, and raise the overall channel bed slope and sediment transport capacity of the lowermost ~100 km of the channel. This measure has the added value of distributing sediment to different locations along the river-deltaic coastline, promoting land growth and minimizing effects of sea level rise. These engineering practices are, in essence, large-scale fluvial experiments that have no modern system-scale analogy. Evaluating the efficiency of these practices is therefore critical, because the practices that promote the long-term sustainability and societal development of the Yellow River deltaic landscape are exportable to other fluvial-deltaic systems that are undergoing rapid land-loss due to natural and anthropogenic factors, for example the Mississippi River.

Figure 2: Collecting samples in the Yellow River with Brandee Carlson. Photo by Andrew Moodie.

A fully synthesized 1D-fluid, quasi-2D delta evolution model that simulates individual delta lobe development (e.g., new lobe in Fig. 1a) and the overall planform or "bird's eye view" development of the delta enables the evaluation of management schemes for a fluvial-deltaic system over a range of important timescales (decades to millenia). The 1D numerical framework explicitly models channel bed aggradation and channel lobe progradation that determine the location and timing of avulsions. Following an avulsion in the model, sediment on the floodplain and beyond the radially-averaged planform shoreline (i.e., sediment in the delta lobe) is redistributed across the delta topset and along the shoreline, respectively, simultaneously prograding and aggrading the 2D delta system. The model is validated by a robust dataset of satellite-derived and historically measured delta development metrics for the Yellow River fluvial-deltaic system. Changing model parameters allows simulation of the effects of different delta management strategies (for example, the WSDR) on the short- and long-term evolution of the delta system, at both the lobe and delta scale. For example, it is possible to produce numerical experiments that test the effects of various sea-level rise rates, ground-fluid extraction rates, flood engineering, or sediment supply changes on the development of a delta.

Results of this analysis confirm that explicit accounting of avulsion processes in a quasi-2D model framework is capable of capturing delta development patterns that otherwise are not resolvable based on previously published delta building models. Instead of allowing an avulsion to occur naturally, we built a numerical experiment that periodically triggered engineered avulsions at strategic locations chosen to maximize the land building potential of the delta system and occurring during engineered flood events, simulating the WSDR project on the Yellow River. Our experiments demonstrated the ability to deliver the necessary sediment to the entire coastline, while controlling the threat of catastrophic flooding interfering with a society developed on the delta. By this result, the implications of this research are in agreement with recent research that supports the feasibility of utilizing river diversions to promote land building in the deltaic environment.

Societal development and natural deltaic processes will continue to be at odds to one another, but recent research out of the process-based sedimentology community supports the notion that coastline stability and a prosperous society are not mutually exclusive, despite a historic record of land use and policy development that have led to land loss across many deltaic landscapes. The Yellow River delta offers a study location for scientists to observe the development patterns of an anthropogenically influenced delta over a short period of time (years to decades). With consideration to the longer timescales of delta dynamics of other fluvial-deltaic systems (e.g., channel lobe switching), the best practices for promoting the long-term deltaic sustainability identified in this Yellow River system research can be applied to the management of deltas around the world. Informed engineering of fluvial-deltaic systems shines as a promising path toward a stable condition able prevent coastal land loss but still accommodate an ever-growing global population and demand for resources.

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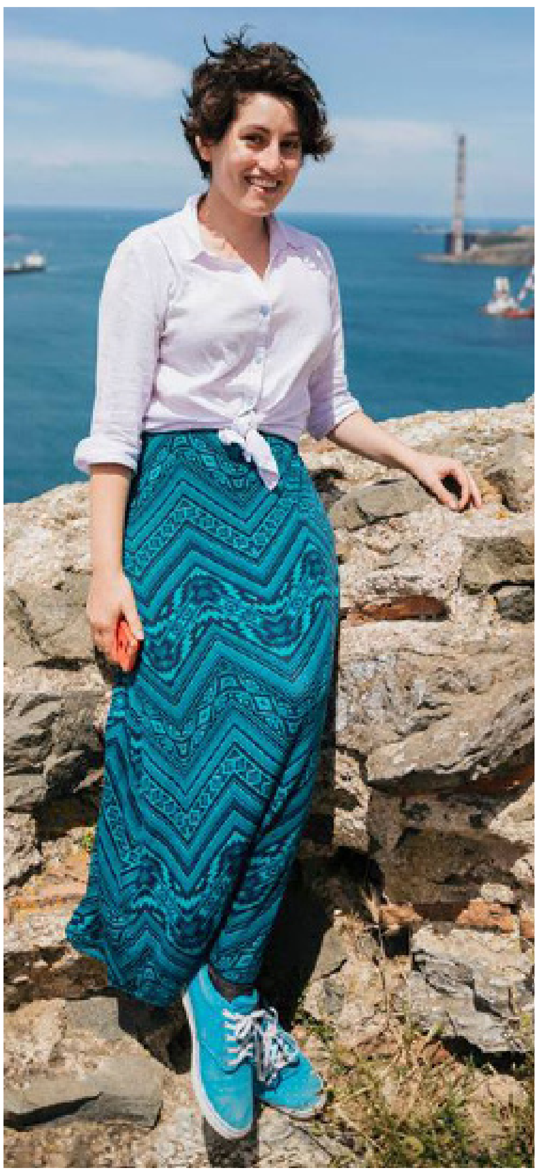
Andrew Moodie is a 3rd year PhD candidate in sedimentary morphology, advised by Dr. Jeffery Nittrouer.

Geo-ARTists

Rice Earth Science is known for its outstanding research scientists... but other talents are also hidden within the department offices.

Lexi Malouta and Nur Schuba show us their gift for creative expression



Lexi, Spain

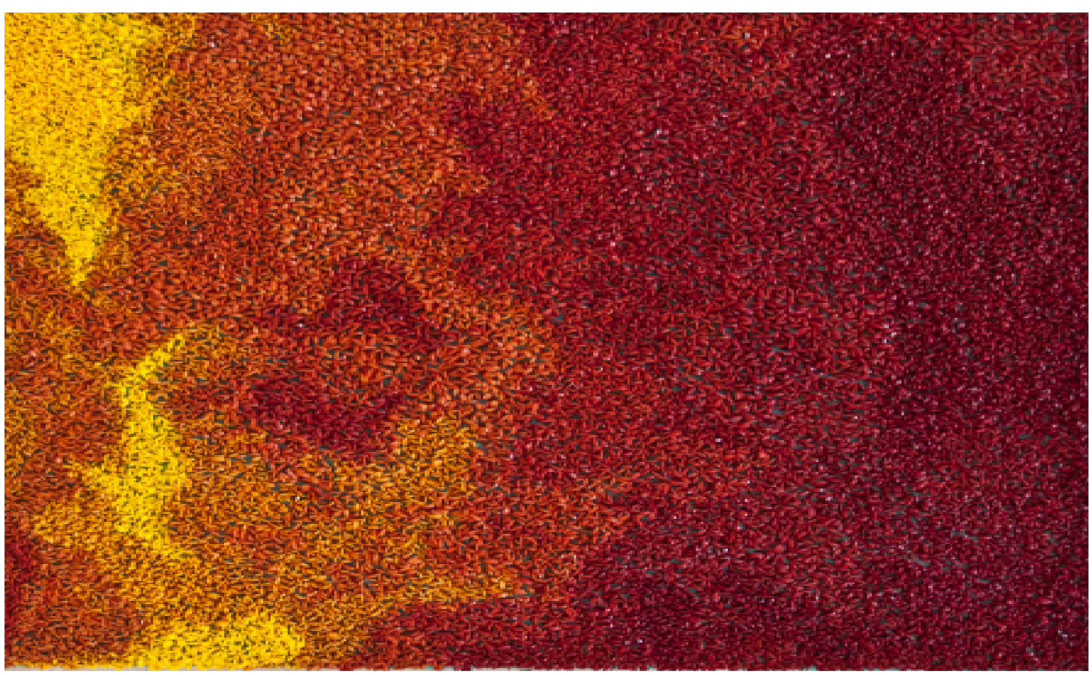
Geode and Cracks, from PAINTINGS

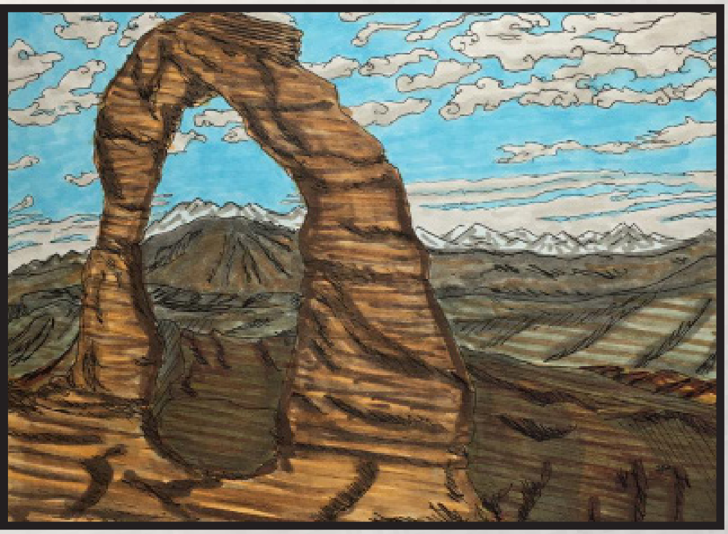
Lexi is a 2nd year Masters student studying serpentinites and peridotites in collisional and subduction zones. Here she gives us a glimpse into the synergies between art and geology.

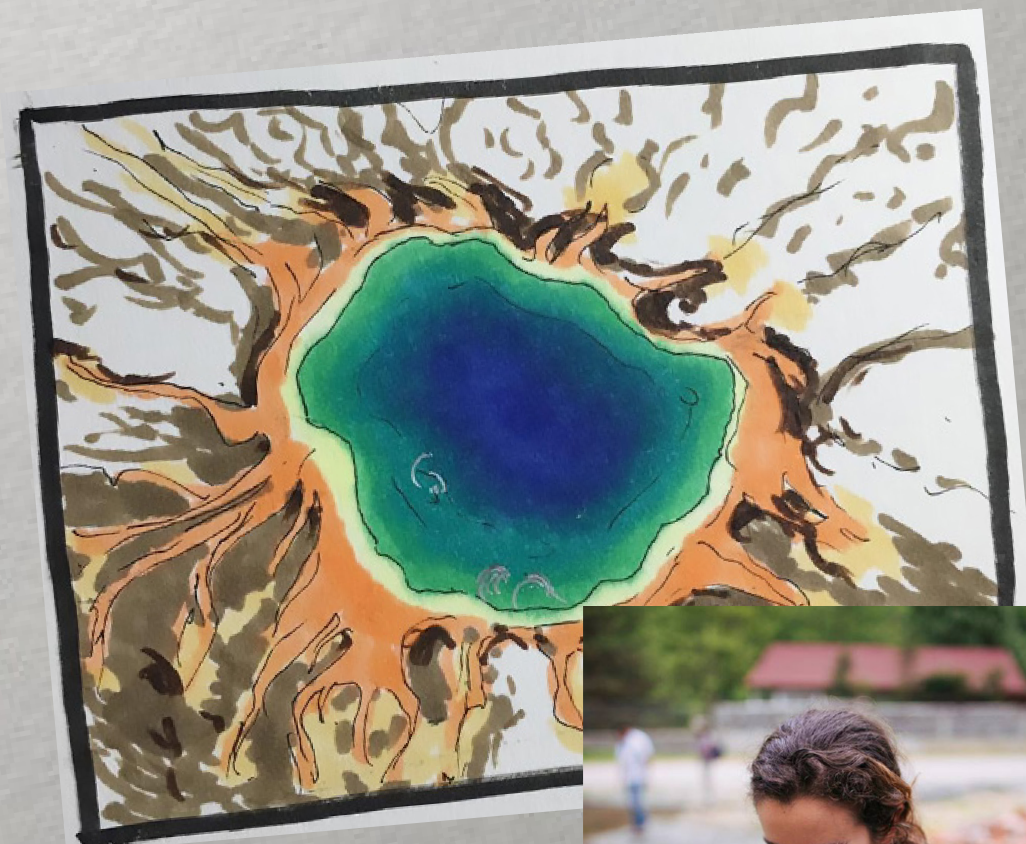
I've always been fascinated by the physicality of the natural world; gravity kneading apart spiraling galaxies, violently pressurized volcanic explosions, flowing rivers and glaciers carving new landscapes, sudden cracking of continents or supple bending of hot rocks. These phenomena inspired me to emulate these processes using acrylic paint for my senior thesis exhibition, PAINTINGS, which was on display in April 2012 in the Zilkha Gallery at Wesleyan University, CT. Each piece's final form was determined largely by process, rather than aesthetic, which gave my art an objective, scientific quality while maintaining visual mystery. Geologic inspiration took my creativity to places I would have never otherwise explored, and in turn, I began to deeply research geologic topics that informed my art. Being in Rice's dynamic environment has inspired my future work; in seminars, classes, and field trips, as I learn about new processes and methods, I make notes of new painting ideas. Even common natural occurrences, when seen in a new light, can be inspiring.

Veins, from PAINTINGS

Barite, from PAINTINGS







Nur Schuba is a second year PhD candidate who recently submitted a paper titled "New-characterization of the S-reflector from Galicia Margin, offshore Spain."

In her free time she uses marker and pen to capture the beauty of geology and nature on paper.

Words with a recent Rice graduate:

Tierra Moore on where she was, what she's doing now, and why she cares

Tierra, you graduated from Rice last year and now I hear that you're doing a Ph.D at U.Penn. What are you going to study?

I'm studying biogeochemistry as an extension of the work I did with Dr. Masiello at Rice. In particular, I'm doing a project on carbon storage and cycling as it relates to anthropogenic dark earths.

What's an anthropogenic dark earth?

I like to think of it as a dynamic metric. Essentially it's charred waste products that ancient people used and buried, which accumulated in the soil over time. It's fundamentally an artifact of human development recorded in the soil. Burned food, waste, housing—after sitting in the Earth for a time they create soils with unique properties.

What properties?

These soils are very fertile and labile, meaning there are a lot of available nutrients for plants. This has impact on the carbon cycle. They are very stable too – carbon doesn't break down in these soils (e.g. they are highly recalcitrant), and store carbon. People usually think of soils as either labile or recalcitrant. Usually they aren't both. But dark earths exhibit enhanced carbon cycling and carbon storage. In my lab we want to understand how both properties exist in the soil mechanistically.

You've got four very full years ahead of you in Philly. What do you hope to have at the end of your studies?

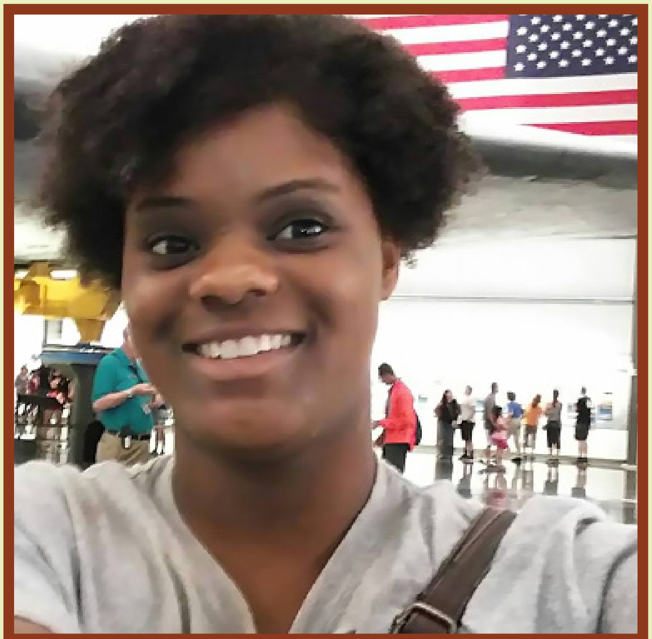
I hope to have a deeper understanding of biogeochemistry and especially the mechanisms driving carbon storage and cycling in soil. I ultimately want to apply that knowledge to build sustainable agricultural systems. I also want to integrate my research into policy issues. I want to become an expert on soil carbon flux, but I also want to use my research to do something that is tangible to me. This will entail me pursuing policy-related extracurricular opportunities throughout my time in grad school. I plan on joining the Science Diplomacy Club, and am applying to be an Intercultural Fellow at U. Penn. I would love an opportunity to work at an environmental think tank after I graduate. This will allow me to blend my research and policy experiences.

You've talked a lot about wanting to apply your science. So, what's your opinion about the current state of connection between scientists and the public?

There's a disconnect between common needs and scientific research – scientists need to make a bridge so that their science is useful. This is where I see policy coming in. Scientists and policy makers need to come together to talk about resource regulation and restoration. The two fields need to communicate more, in my opinion, and I intend to lead endeavors to do so.

As a recent (very successful) graduate, I must ask: If you had one piece of advice for undergraduates what would it be?

Always aspire to challenge yourself. You're worth that challenge, and it will help you grow. Also remember that no matter how much you enjoy science and your major, there will always be frustrations and you may want to give up…if only for a moment. Remember that it's supposed to be hard. Adversity is normal and overcoming it makes you stronger. Just keep pushing that rock up that hill. You'll get there one day, and you'll be proud of all the work that you put forth.



Tierra Moore is a second year Ph.D student at the University of Pennsylvania. She graduated with a B.S. Earth Science from Rice in 2015.

Interview by Larisa LaMere

An interview with Melodie French

"I used to set up a chair in my closet and solve long division problems with a marker on the wall. The numbers stretched from the ceiling to the floor."

WE WANT TO KNOW

Before we get down to buisness, I have to ask. Before you got to Rice much of your research focused on the San Andres Fault. So, is California going to be broken off by a major earthquake and float away soon?!

Probably, which is another reason Houston is a great place to live! Seriously though, no. The San Andreas Fault system occurs along the boundary between the North American and Pacific tectonic plates. Most of California is on the North American Plate, but south of San Francisco the fault trends inland and many coastal cities are on the Pacific Plate. In a sense, the region of California on the Pacific Plate is already floating away from the rest of North America, just very slowly and inefficiently. It is slow because the relative plate velocity is only about 50 mm per year and inefficient because the plates are moving nearly parallel to the plate boundary. The reason earthquakes do not influence this process is that tectonic plates consist of the entire lithosphere, which is on the order of 100 km thick, but along transform fault systems like the San Andreas, earthquakes only occur in the upper 15 km of the lithosphere. Only the very top of the plate boundary is fracturing and sliding during an earthquake.

TELL ME ABOUT YOUR MOTHER

My mom works in low-income property management, a career that requires equal parts grit and heart, not unlike academics. My mom was very supportive of me when I was young, but I didn't have access to science camps or enriched learning programs in the small town where I grew up. In normal school, I was really drawn towards math, more than anything else. I remember when I first learned long division. I set up a chair in my closet and solved long division problems with a pencil on the wall. The numbers stretched from the ceiling to the floor. For high school, I attended a state funded boarding school for math and science in a remote part of northern Maine. When I got to college, since I had liked math for so long, I thought I would major in it. And for my first year it was great, but before long I didn't relate to the problems we were solving anymore. It was learning about numbers for numbers sake. By the end of my first year I switched my major to physics. I had taken some physics classes in high school and really enjoyed them. And I thought physics was the place where I could use math but keep solving problems. But before long, physics started to feel a little too obscure for me too.

I added a minor in geology after starting to take geology classes later on in my undergrad. That was the first time I got exposed to earth science. I was lucky to have a research opportunity with a structural geologist. That was fun for me -- it was a way to integrate several fields to solve complex problems. When I decided to get a Master's, it was this topic that I decided to pursue.

What's funny about being a geologist now is that I grew up in a really geologically interesting area in Maine, but I didn't care about trying to understand the rocks. They just looked messy to me, a bunch of jumbled up features with no pattern or any rules. I did like nature (I spent a lot of time hiking around and exploring in the woods) but the earth wasn't something I felt drawn to study. Even until I started my graduate degree, I didn't fully realize that I could use math and physics to understand rocks. What I learned and keep learning is that every rock records a story. And I can back-solve the story like a complex math problem (even though it might not look exactly like long division).

And after all, it turns out that I am doing the same things I liked to do when I was little. I really like being in the lab and working with my hands to build equipment and run experiments. And I really like making physical models to fit the data I collect. Those are my two favorite parts. The only part I don't like at all about what I do is the part where I have to organize data. Spreadsheets? Nope. I hate them.

ONE THING LEADS TO ANOTHER

Even though many of my interests have stayed the same over the years, my path certainly wasn't straight and narrow and, as a result, I have been influenced by lots of people. When I finished my bachelors, I got a job at a shop fixing bicycles for half a year. Then I worked for half a year in a national park installing piezometers for education-outreach programs. That was before I started my Masters. In between my Masters and Ph.D, I worked for a while as a laboratory technician (getting paid more, and with less stress than I would have as a grad student! It didn't seem quite fair).

In my first year of grad school, after being a physics major, I had a weaker geology background than my peers and I was insecure about this. I learned a lot though, from my peers and professors, and my time with that group still influences what I do today. Slowly I made my place among the geologists, especially as I realized that I really only had to understand the system I was working on to contribute immediately, and that I could build breadth over time. I suppose the lessons I learned from my early graduate career are that it is important to see a project through carefully and rigorously, even if it becomes clear that this work will not be your life's work, and that is equally important to follow your interests to new fields and methods, even if it means losing the advantage of expertise.

I didn't commit to a career in academics until a couple years through my Ph.D, I really enjoyed the intellectual freedom I had as a Ph.D student, and the projects I had started -- researching fault deformation and the role of fluids – were rewarding, but I tried to keep my career options open. Giving up research was never an option, and I like to teach quite a bit. I began to realize that an academic career might be really satisfying for me. But I held off committing to professor-ship as long as possible and followed my interests rather than a prescribed career path.

NEW ADVENTURES

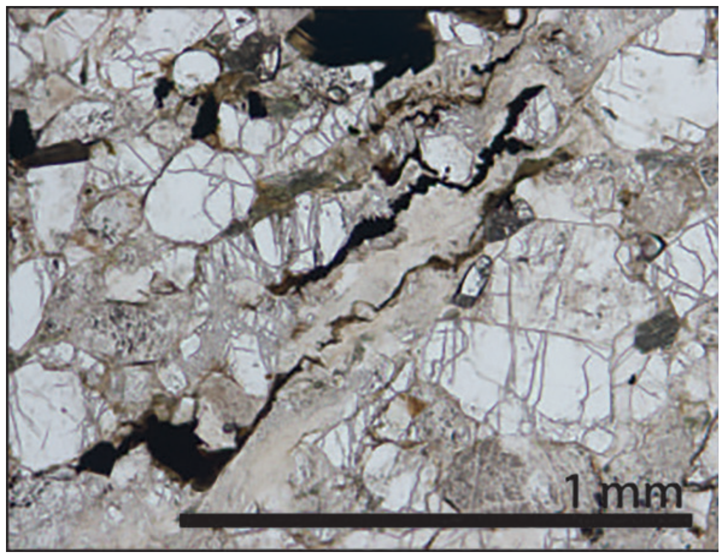
I am excited to build a lab of my own and to facilitate a group of people interested in fault mechanics. And I'm also excited to use the time I have before I start teaching to write and start new projects. I am also both eager and nervous to start teaching and contributing to the curriculum here at Rice. Recruiting graduate students is a little bit nerve-wracking. I've never questioned before whether the work I do is work that other people would care about doing, too. It's scary and exciting to have that ahead of me.

Interview by Larisa LaMere

DO WHAT YOU LOVE AND LOVE WHAT YOU DO

I like knowing that my work is relevant to society. Earthquakes affect people. I study the physical processes that cause earthquakes to begin, grow, and arrest. The relative importance of these three stages determines whether an earthquake occurs at all and how big it may become. Here at Rice I plan to conduct experiments and study natural faults to look at two variables in particular that control these stages: (1) fluids in the pore space and (2) physical heterogeneity in fault structure. Right now scientists are realizing how much more we have to learn about faults in general. Our models don't always predict what happens in the natural systems. We are often taught to think of faulting as occurring along planes, and in many cases a planar fault is an appropriate and powerful model. But fault zones are actually tabular – zones or regions where physical and chemical processes accommodate faulting – and the structure and composition of these tabular zones can have a great effect on the three stages of earthquake development.

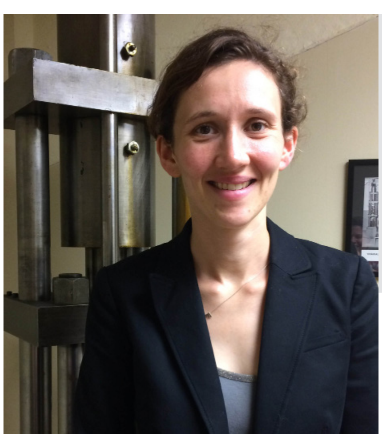
When people ask me what I do I usually talk about seismic hazards in general and I don't volunteer many details, because I work at a very small scale and most people must more easily visualize large scales. See, though, I love the details of what I do. And in hindsight I can see that I have always been drawn to the details. As a kid I was a problem solver. I took apart and rebuilt broken bikes and did complicated long division. And now I am a problem solver. I start from all the individual pieces to build equipment and experiments and models, to fit to data. My advice to anybody is to enjoy how you spend your time, surround yourself with good people, and let that lead you.



Fractured low-porosity (7 %) and low permeability (~10-19 m^2) arkosic sandstone. Photo credit Melody French

HOUSTON MATTERS

I really like to bike. I'm hoping to get to continue that because my new house is close to one of Houston's bike trails. My new yard is great for gardening. Also my spouse and a few of our friends live in Houston and work in Oil and Gas, so I'm sure they will show me around town and help me find things to do!



Melodie French will begin her professorship in the Spring of 2017

Interview by Larisa LaMere

Laurence Yeung documents how paying attention pays off

One of my favorite things about lab work is the opportunity to be creative in tiny ways. These "lab tricks" often go undocumented, though, so they are often lost to the ether when lab members move on to bigger and better things. The Yeung Lab's attempt to alleviate this problem will be occasional posts about challenges we've encountered and how we addressed them, which we hope will also help and amuse our fellow intrepid lab rats elsewhere. Today, I'll tell you how we slow down the leak rate on our vacuum sampling vessels so we can store them for up to six months—by filling up the valve stem with water.

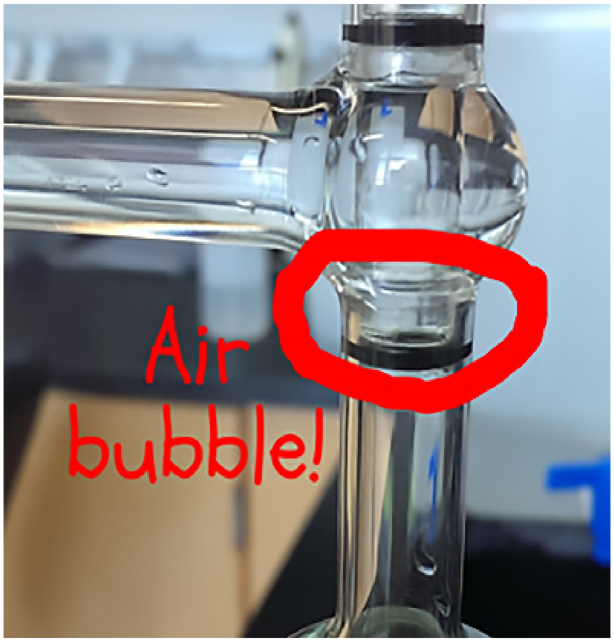


Figure 1: The enemy

It's not as simple as you think. Because of the tight tolerances in high-vacuum valves and the presence of waxy vacuum grease, water does not like to wet the part of the valve right next to the o-ring seal. Unfortunately, it is also the most important area to get wet: A bubble there is as bad as having the valve exposed to the atmosphere.

The challenge, then, is to get rid of all the air bubbles in the valve, and to do it efficiently. We had about 32 vessels to prepare for this round, and many more in the future, so it was an important problem to solve.

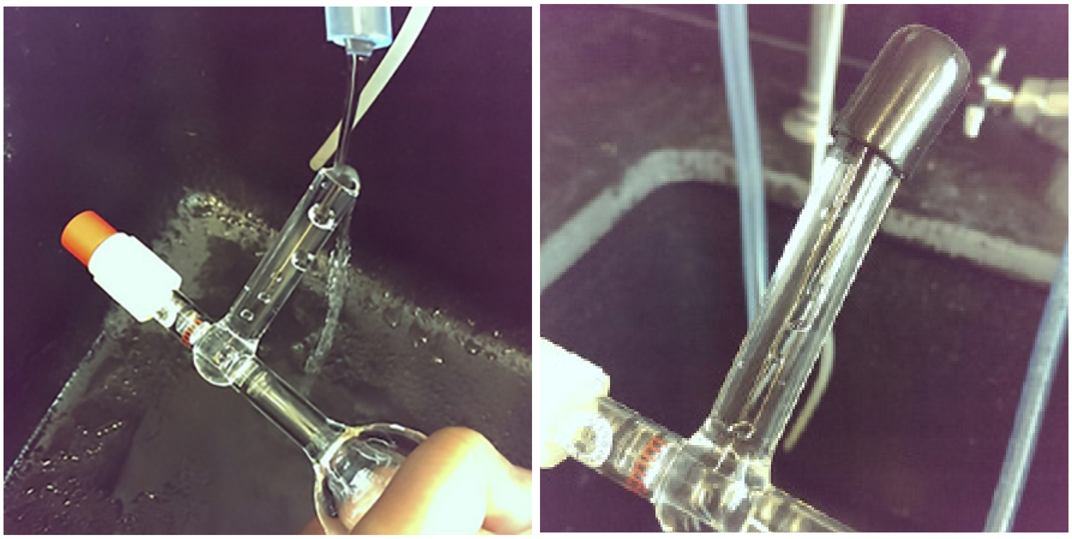


Figure 2: Filling and capping the stem

I was originally taught to tap the neck of the bottle on the table until the bubbles came out. While it is a reasonable technique, its ineffectiveness became quite apparent as I was teaching my grad students how to do it. We were all having a lot of trouble tapping with enough force to dislodge the bubble without risking breaking the glass. So I found another solution.

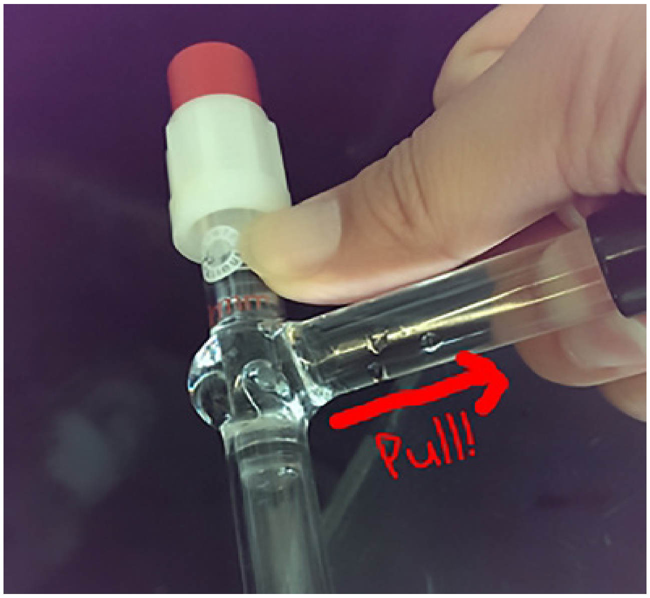


Figure 3: Pulling out air bubbles.

We use a PVC endcap, which is usually only added when we're done to keep the water in the stem, to our advantage. After filling up the stem to the brim, we push the endcap on. The close fit between the endcap and the stem results in some resistance when pushing the cap on. This is a good thing.

That resistance indicates that you're making a weak seal with the valve stem, which can be used to pull the bubbles out.

We pull the cap off quickly (see Figure 3). It makes a satisfying "pop" sound. That's the sound of the suction generated, which dislodges the bubble and may even degas the water a little (like when you open a bottle of soda). A bit of water often comes out of the stem but that's okay—it's just the cost of doing business, and a small price to pay for efficiency.

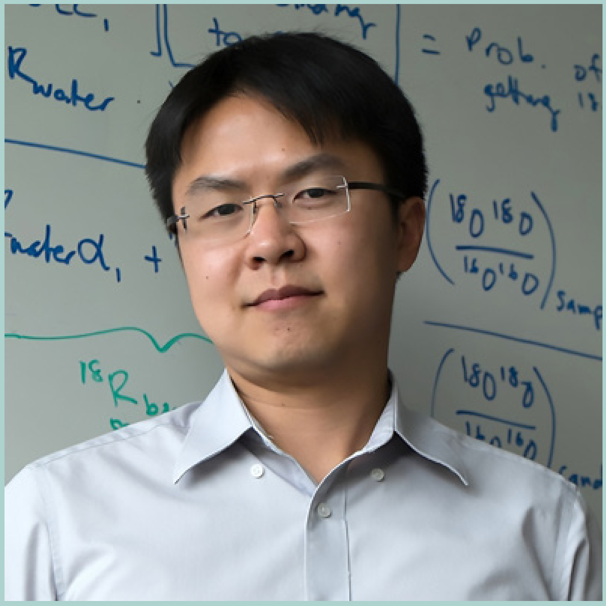
Figure 4: Stem filled with water and no bubbles. Success.

We found that the stem needs to be filled to the brim. The technique relies on the fact that air is compressible and water is not; if there is an air bubble at the tip of the stem, all you'll end up doing is compressing and decompressing that top bubble, and not any of the bubbles inside the stem.

Even with this technique, we found that we have to refill the stem and go about 5 or 6 cycles per bottle before all the bubbles are out. Yet, it is still much faster than the tapping method; I'd say maybe by 3 times or more. And that really pays off when you've got many bottles to pack and take to the field.

Figure 5: Bottles galore

Laurence Yeung is an assistant professor in the Earth Science department, an expert on clumped isotope geochemistry and mass spectrometry, who has a passion for precisely conducting laboratory and field studies and collecting data on atmospheric and ocean chemical processes.



Earth Science at Rice University

Message from the chair

The Earth science department at Rice is a community of professors, adjuncts, students, post-doctorates, staff and friends - over one hundred of us - whose primary mission is to educate, communicate and conduct fundamental research on problems of Earth, energy and environment. Our community extends outward to hundreds of alumni, who have gone on to pursue diverse careers, including in academia, the energy industry, environmental consulting, medicine and health, politics, community organizing, teaching, and more. As Earth scientists, we excel in making observations and interpreting complex, open-ended systems. We see the world, because nature is beautifully complex, as an interconnected system, with moving parts that feed and respond to one another. From understanding how interactions between the deep Earth and surface modulate climate to investigating how erosion, soil formation and life shape the surface of the Earth and our immediate environment, we acquire by necessity a unique mind-set through our training and experiences, giving us key advantages in tackling some of the most complex, uncertain and controversial problems facing science and society.

With our flavor of Earth science, we emphasize understanding at a fundamental level. We teach our students to approach all geologic and environmental problems from a process-oriented approach and to consider Earth as a system. We do so by coupling field observations and laboratory analyses with quantitative modeling and experimentation. In Earth Science, we draw on physics, chemistry, math and biology in our investigations of our planet and environment. We have some of the best, award-winning faculty in the world, but what really sets our department apart from others is our ability to work together and generate interdisciplinary projects that could not otherwise be accomplished by any single faculty alone. Our department has become one of the country's most successful leaders in Earth science innovation. We as Earth scientists, especially with the Rice approach, are uniquely poised to tackle the most complex problems facing our society today. One such problem is developing aggressive energy portfolios and economies while at the same time developing programs for sustainable environment and health. There are no easy solutions. Any solution will require the unique skill of looking at the problem as a system of interconnected parts, a skill that is uniquely Rice Earth science.

A diverse research portfolio

We have expertise in deep and surface Earth processes. In deep Earth, we are investigating deep volatile cycling, core formation, the structure and composition of the crust and mantle, mountain building, volcanism, plate motions, basin formation, crust and lithosphere deformation, mantle convection and earthquake physics. We are also growing our expertise in planetary science, including the petrology and geochemistry of meteorites, geodynamics of planetary interiors, and processes of planetary accretion. In the surface Earth, we are tackling problems related to paleoclimate, atmospheric chemistry and dynamics, elemental cycling, weathering, upland and fluvial geomorphology, sedimentology, biogeochemistry, geobiology, stratigraphy, paleo sea-level reconstruction, tempestology, and cryosphere studies.

Our research has appeared in high profile journals like Nature, Science and the Proceedings of the National Academy of Sciences. You may have recently heard about new constraints on the timing of retreat of the Antarctic ice sheet, a new theory on the evolution of atmospheric oxygen, new clumped isotope tracers of biochemical processes, a new understanding of the origin of copper porphyries, how the Caribbean margin evolved, what happens to the Pacific plate after it subducts beneath Japan, the role of carbon in controlling melting in the upper mantle, or how we need to revise our views on the sand budgets in rivers. These came from our faculty and our students.

We are a fundamentally interdisciplinary department, with a number of us leading large, collaborative programs that bring together several scientists here in our department as well as scientists from other departments or other universities. Ongoing multiple principle investigator programs include National Science Foundation-funded projects to investigate carbon and oxygen cycling between the deep Earth and surface environment, sediment transport in the Yellow River in China, lithospheric and crustal structure in slow spreading centers off of Spain, lithospheric stability beneath the western Mediterranean, lithospheric structure in the Columbian Andes, lithospheric structure of east Asia, and the history of ice sheet advance and retreat in Antarctica. Our faculty also lead a million dollar Keck Foundation project to develop biosensors for interrogating biogeochemical processes in soils and sediments. We also play key roles in leading International Ocean Drilling Program expeditions, with the latest one headed to the southwest Pacific to investigate the evolution of subduction zones at a continental margin. We are arguably one of the most interactive and holistic departments in the country.

We have an applied dimension to our research portfolio as well. Some of us are in the business of developing algorithms for handling geophysical data while others develop methods for quantifying the physical, chemical and mineralogical properties of soils and sediments, all of which have implications for the energy and environmental industries. Many of our research projects are also focused on natural resources. These include characterizing and understanding the origin of hydrocarbon source rocks and formation, ore formation, water resources, and sand transport. We have ongoing research in natural hazards, such as understanding the physics of earthquakes and volcanic eruptions, reconstructing the spatial and temporal distribution of hurricanes along the Gulf Coast, and understanding how landslides form. Finally, we have active research on environmental problems, such as delta formation and evolution, river morphology evolution, the chemistry of soils, carbon sequestration in soils, atmospheric pollution and heavy metals in urban waters.

Our research has taken us to all corners of every continent, while others develop numerical models and techniques to simulate geologic processes or develop cutting edge experimental and analytical facilities to push the limits in terms of precision or resolution, allowing us to "see" things we were not capable of a decade ago.

Educating the next generation

We pride ourselves in our teaching. Our classes are small and we try to teach our students about the complex world around us, while at the same time, teaching students how to simplify a complex problem into the key components. We do this by emphasizing the big picture, through field trips across the country, and at the same time, teaching basic technical skills through hands-on learning of computer modeling and laboratory analyses and experimentation. Many of our courses emphasize writing, communication and independent thinking through term papers and oral presentations. As students complete their core classes, they participate in research seminars, where all the topics of discussion are open-ended. Some courses bring together several faculty with different views to tackle a common problem, giving students experience in interdisciplinary research and how science operates. Many of our students participate in undergraduate research, giving them direct access to laboratories. In some cases, these undergraduate research projects have led to first-authored papers. Each year, we send many of our students on to graduate school, some of them winning the much coveted National Science Foundation Graduate Fellowship. Regardless of where our students go in the future, the hard and soft skills they learn here prepare them to be leaders.

Equipping our students for success

Our success in education and research is in part linked to the health of our facilities. Over the last decade, we have increased our analytical facilities through support from the National Science Foundation, Packard Foundation funds, and endowment funds. On the third floor, we now have gas source mass spectrometers, a laser ablation facility coupled to an inductively coupled plasma mass spectrometer, a fourier-transform infrared microscope, a field emission electron microprobe, and an X-ray fluorescence imager. We have the ability to do U/Pb geochronology, traditional stable isotopes, clumped isotopes, and trace and major elements, and speciation in a variety of materials. We also have the ability for elemental mapping at a variety of lengthscales ranging from the centimeter to nanometer scale. On the second and third floors, we have a variety of apparatus for simulating extreme conditions on Earth and other planets, studying the rheology and dynamics of fluids, and characterizing the physical properties of soils. These instruments are utilized by both graduate and undergraduate students.

Where are we going?

We cannot rest on our laurels. Earth science is continually changing, so we must continually adapt and improve to position ourselves for continued success in an unpredictable environment. It is the long vision that matters. Here are some of the initiatives we are currently developing or hoping to embark on in the next year to give you an idea of where we are headed.

A growing and evolving faculty – This past year, we were sad to see Brandon Dugan leave, but we are happy that he is starting new adventures at the Colorado School of Mines. In the meantime, we conducted a successful open search. We received over 300 applications, with our top two applicants accepting our offers. Melodie French will join us in January 2017 from the University of Maryland, where she is an NSF post-doctoral fellow. She is a rock physicist working on material and transport properties of fault-related rocks and sediments. She will enhance our strengths in Earth structure and deformation and our ties to the energy and environmental industries. Mark Torres will join us in September 2017 from Caltech, where he is currently a post-doctoral fellow, working on chemical weathering, geomorphology, and surface cycling of sulfur and carbon.

In addition to Melodie and Mark, we will be conducting another search in the next couple years. We have a number of fields that interest us, including but not limited to geobiology, paleoclimate, mineral physics, environmental science earth history, stratigraphy, cryosphere studies, planetary sciences, tectonics, geophysics, and water resources. In the end, we just want open and creative minds around us.

Bringing industry and academia together – Our previous chair Richard Gordon along with distinguished alumni Ken Abdulah and Ed Biegert established a Rice industry-academia workshop called IRESS (Industry-Rice Earth Science Symposia) to help foster better ties between Rice and industry. Building on the successes of the last three symposia, we have decided to expand the scope and vision of the symposia. Our primary goal is for Rice Earth Science to serve as a think tank, which brings the best ideas from academia and industry, from around the world, to solve challenging scientific problems. Our goal is to serve as the catalyst for cross-disciplinary interactions and eventual collaboration. IRESS 2017 (earthscience.rice.edu/iress), Feb 23-24, will focus on a theme entitled "Interdisciplinary perspectives on the building of a passive margin", and we have already built a list of distinguished speakers, covering topics from continental rifting to new concepts in tectonostratigraphy to sedimentology on Mars. This event will redefine our understanding of passive margin development and is one event you definitely do not want to miss.

Generating an integrative department – One of our goals is to build a more cohesive department. With over one hundred current members in the department, many of whom travel around the world for field work or conferences, it is challenging to have department-wide meetings and activities that keep everyone informed of each other's activities. This becomes even more challenging if we add to this our desire to interface with our alumni and friends. As a first step towards these goals, we implemented last summer a new webpage platform (earthscience.rice.edu) whose content is controlled by all members of the department and no longer requires a webmaster. This webpage is our portal for departmental activities, recent publications, news items, and blogs from our students, updating in real time. In the coming years, we hope to bring the webpage to our alumni and friends, giving them the opportunity to share their own stories and become more engaged with our department.

Experiential learning – Earth science classes are unique in that we consistently work on open-ended problems and provide hands-on experience by sending our students to the field or into laboratories. We have been successful at this, but there is still room to grow. Provided we have enough funds, we hope to expand the field components of several classes. We have developed a new senior honor's thesis program and we are looking to set up internal research funds for such students to execute their ideas. With adjuncts and our faculty, we will be adapting and developing new courses that emphasize working with disparate datasets, seeing Earth as a system, and cultivating teamwork, skills that are useful in academia and in industry. Finally, we are in the midst of developing writing courses to help our students communicate more effectively.

Science communication – In the coming year, we will be hiring a dedicated science writer. The science writer will help promote our department by writing about Earth science research in our department and beyond in layperson terms. We are looking for creative, highly motivated individuals whose mission is to bring science and the process of doing science to the broader community. If you are interested or know of anyone that fits this bill, contact us!

Enhancing our analytical and computational facilities – The strength of a research institution depends on generating great ideas and being able to execute those ideas. Analytical and computational facilities are critical in this sense as they allow us to generate data. Through the writing of proposals to NSF or NASA, we hope to acquire major instrumentation infrastructure that positions our department as a facility where investigators from industry and academia visit. These include quantitative isotopic, elemental and mineralogic imaging facilities, such as secondary ion mass spectrometry and hyperspectral core scanners. Of high priority will be to establish the necessary technical support to operate and maintain our facilities in prime condition for the future.

Career development – Earth scientists in theory have many career options. We will continue to cultivate and enhance our ties with the energy industry. As part of these efforts, we will hold workshops where alums from industry return to share their career paths with our students. We are also interested in getting the perspective of alums who chose to start their own businesses or took career paths not directly related to Earth sciences: medicine, government, art, writing, etc. We are also committed to supporting the careers and initiatives of women in Earth sciences, which has traditionally been a male-dominated field.

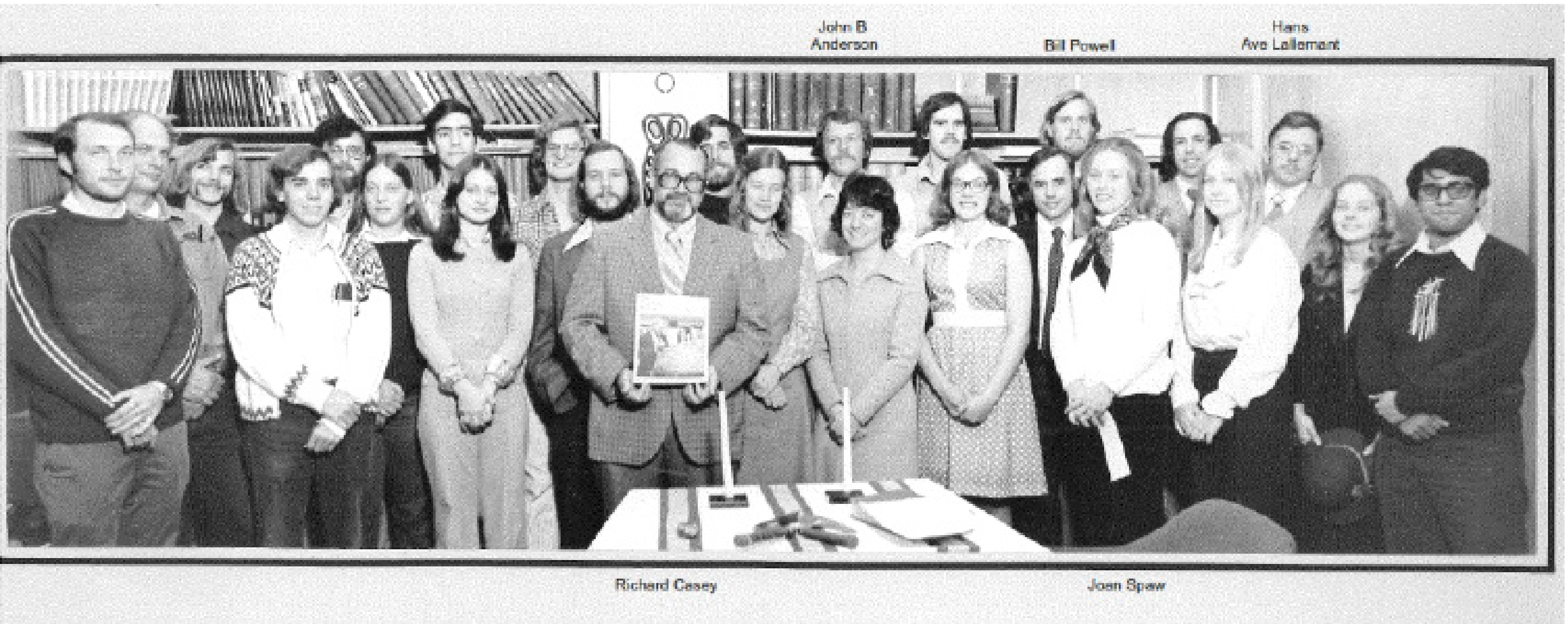
Alumni activities – We will be embarking on a number of Department-sponsored activities over the course of this year, ranging from one day birdwatching trips with Pete Vail to weekend trips led by Andre Droxler out to the Guadalupe Mountains or Texas Hill Country. We will also be experimenting with new alumni trips focused on geology and natural history.

You are part of our community

As you can see, we have set many lofty goals to keep us ahead of the pack. We aim to build an energy-academia think tank, establish new courses for experiential learning, enhance our facilities, expand the size of our departmental faculty and train the next generation of critical thinkers. And we want you to be involved. This takes a variety of forms. You can give to our research, innovation and education funds, existing endowments, or you can establish your own endowment and directly help shape and guide the future of our department. You can also volunteer your time by sharing your experiences with our students and help them navigate their own career paths. Or you can just join us on any of our departmental activities and share with us your experiences and ideas. We are always open to learning new things! Now is the time to join us and help Earth sciences at Rice rise to its full potential.

Sincerely yours

Cin-Ty Lee, September 2016



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AAPG RIGS

September 23rd and 30th

A FLAGSHIP EVENT OF THE AAPG RICE STUDENT CHAPTER

The AAPG Rice student chapter and IRESS invite all alumni and friends of the department.

SEPTEMBER 23rd: Student talks on the 2 Big G's (Geology and Geophysics).

SEPTEMBER 30th: Open house featuring student posters, new laboratories, and kick off for IRESS 2017 - Continental Margins II: Interdisciplinary perspectives on the building of a passive margin .

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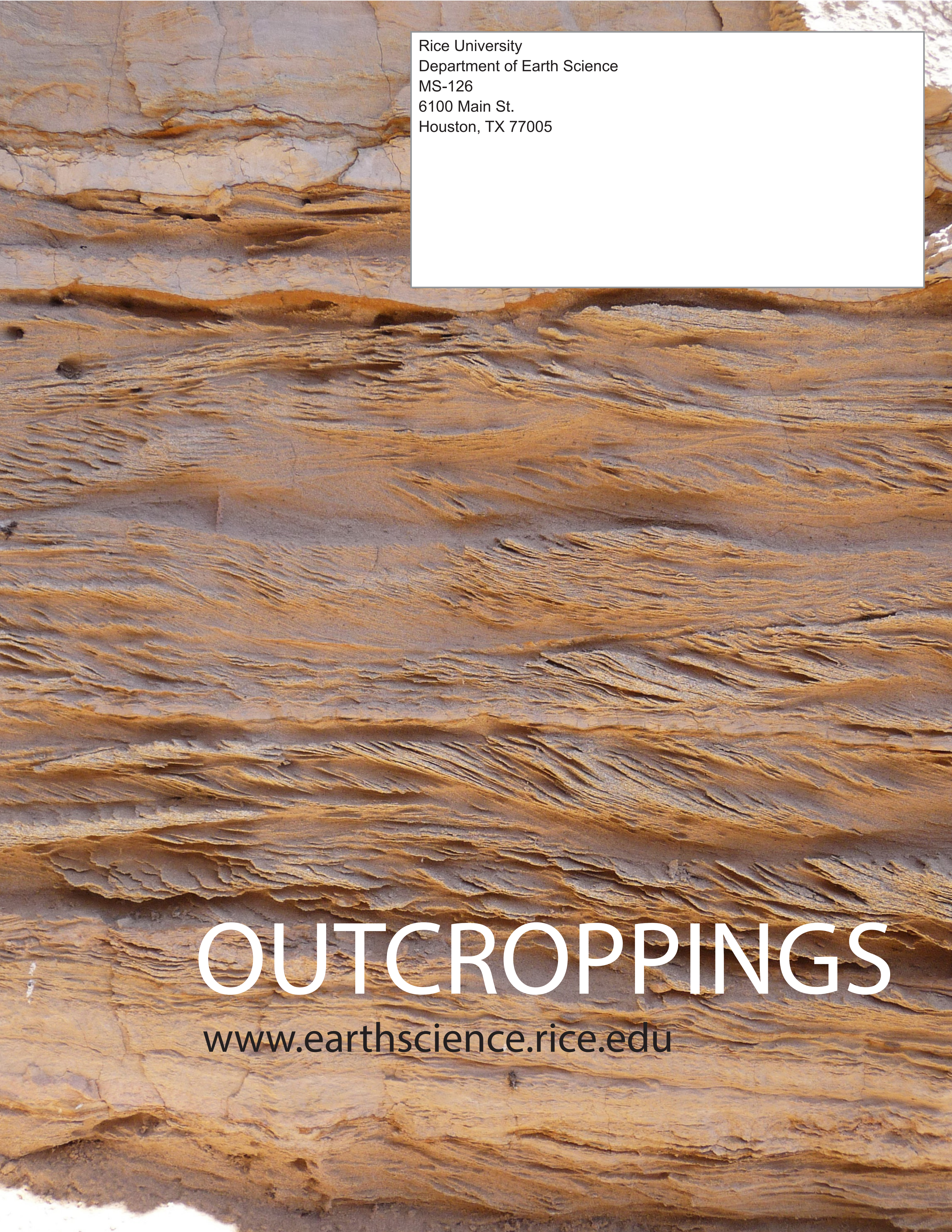

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