Bacterial Polyphosphate Metabolism and the Origin of Phosphatic Mineral Deposits

by Jake Bailey

A farmer adds phosphorus to land in southern Minnesota, her crops grow, and people eat. Phosphorus is a critical element to life. It is used for many biological functions, including the transfer of energy within cells and the stabilization of DNA. But where does that phosphorus come from and where does it end up over geological timescales? Much of the phosphorus used in modern agriculture comes from the processing of several million tons of rock mined annually from deposits known as phosphorites. Phosphorites are sedimentary rocks that contain ca. 6-13% phosphate, primarily in the form of apatite-group minerals (Figure 1A). Phosphorus mining primarily occurs in the United States, China, and Morocco, with deposits of mineable significance also occurring in a few other countries. Depletion of mineable phosphorites, which are considered a non-renewable resource, is a growing concern and new sources of phosphorus are being sought. One potential source of phosphatic material that is receiving interest from a mining standpoint are the sediments in which phosphorites are actively forming today. But what is happening in these sediments that results in the formation of a phosphorite?

Phosphorus primarily enters the hydrosphere through the weathering of phosphorus-bearing igneous and sedimentary rocks. As a limiting nutrient for phototrophic life, phosphorus is rapidly taken up by organisms, and upon death, phosphorus released from biomass is rapidly cycled through the hydrosphere and back into the biosphere. However some phosphorus does make it into sediments, either as particulate organic matter and fish bones, or adsorbed to iron oxides. Phosphorus-bearing minerals are also known to form in certain marine sediments and it is these rare precipitated phosphate minerals that are primarily relevant to phosphorite formation. Decades of research suggest that phosphorites primarily result from the reworking and sedimentary concentration of phosphatic precipitates and grains. However, what is not well understood is why the source phosphatic minerals precipitate in certain sedimentary settings.

The formation of phosphorites in modern sediments primarily occurs in marine shelf

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Greetings from the Chair

Hello from Pillsbury Hall – a very busy place this winter. In addition to all the usual activities related to teaching and research, Pillsbury is experiencing a bit of renovation this winter. Some of the renovation involves fixing critical issues of utilities and infrastructure, and some is related to the temporary relocation to Pillsbury of LacCore researchers displaced from their home deep in the Civil Engineering building while that building is renovated. In fact, there has been a lot of moving around this year: the Polar Geospatial Center, a highly successful research group within our school, needed to grow more than Pillsbury Hall could accommodate and recently moved into new quarters on the St. Paul campus. One thing that is not new in any of this is that our department continues to be dispersed among quite a few buildings on the Twin Cities campus.

Will that ever change? Perhaps... Although this will sound very familiar to many of you, given the number of times in the past when there have been plans or rumors of plans for a new home for our department, we are in the midst of the “pre-design” phase of planning for a possible new home in a renovated Tate Laboratory of Physics. If you have been on campus lately, you may have seen a new Physics and Nanotechnology Building under construction. That new building will house approximately half of the physics department (primarily the experimentalists), and the rest (including the astrophysicists) will remain in Tate Hall, where we may join them after the building has been substantially renovated. There are many uncertainties remaining before we will know whether such a move is likely.

I also have a bit of news to report about the faculty, “old” and new: Two faculty colleagues have announced their plans to retire: Jim Stout (2013) and Calvin Alexander (2014). Stay tuned for announcements about festivities (see page 11) to celebrate the careers and contributions of these colleagues. In the meantime, we are currently conducting a search for two new faculty members: one each in Earth-surface processes and Hydrogeologic processes. The surface processes search has resulted in the hiring of Andrew Wickert from the University of Colorado. Andy (in his own words) investigates the “co-evolution of ice sheets, climate, rivers, sea level, and depositional systems over the last glacial cycle; geodynamics; watershed-scale hydrology and wild fires; landscape evolution in drylands; and the design and installation of open-source instrumentation to monitor processes in the field.” As I write, the search in Hydrogeologic processes is still ongoing.

I sometimes joke that my job as department head mostly consists of signing forms, but one of the things that I sincerely enjoy signing are the thank-you letters to alumni and friends who have made a donation to one of the department’s funds for student fellowships, scholarships, or field experiences, or to the general fund for support of research and teaching. It is fascinating to see the names and addresses of those who support the department in this way. I have greatly enjoyed becoming more familiar with the department’s people and history and gaining a new appreciation for how fortunate we are to have such a strong network of alumni and friends. These donations provide critical support for our field courses and other field experiences for students and supplement research grants to support as many students as possible. In this newsletter, you will read about two new funds: the Allan and Eleanor Martini Fellowship and the Robert and Carol Gunn Professorship (see page 17).

We also have a great need for technician and research-scientist support for laboratories. It can be very difficult to provide sufficient, stable funding from grants for the personnel needed to run these state-of-the-art facilities,

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Field work in the Central Anatolian Fault Zone and eastern Taurus Mountains, Turkey. Donna Whitney and colleagues are currently working on a 5-year NSF-funded Continental Dynamics project to investigate mantle-to-surface dynamics of continents with significant strike-slip faulting, uplift, and volcanism. (project webpage: http://www.esci.umn.edu/orgs/whitney/CD-CAT-index.html)
settings associated with upwelling systems where nutrient-rich waters fuel the blooming of photosynthetic algae. The increased-biological oxygen demand that accompanies the decay of this algal biomass often results in low-oxygen conditions in shelf sediments and bottom waters. One might infer that phosphogenesis is promoted by the increased export of phosphorus from the water column into sediments that accompanies these algal blooms, and this may in fact be an important aspect of phosphogenesis. But the concentration of phosphate in certain sedimentary pore water horizons where apatite is actively precipitating, cannot be easily explained by the simple the breakdown of organic detritus. Gathering evidence suggests that microbial processes may be important for the concentration of phosphate that leads to sedimentary apatite precipitation.

In shelf settings off of Namibia, and in other phosphogenic sediments, pore water phosphate concentrations and precipitation of apatite minerals is closely associated with accumulations of bacteria that acquire their metabolic energy primarily through the chemical oxidation of hydrogen sulfide, which they use to fix CO2 into biomass in a manner similar to plants. Some of these bacteria are giants of the microbial world, with individual cells reaching nearly a millimeter in diameter. These giant cells are adapted to dynamic changes in bottom water geochemistry that can oscillate between anoxic, sulfidic conditions and oxygenated conditions over periods of months. Part of that adaptation involves the storage of various metabolites in granules and vacuoles within the cell. One of these types of inclusions is known to store polyphosphate. Polyphosphates are linear chains of phosphate linked by phosphoanhydride bonds (Figure 2). These polyphosphate molecules have diverse functions in organisms from all three domains of life, including serving as an energy reserve.

The role, or roles, of polyphosphate in marine microbial ecosystems remains poorly understood. However, polyphosphates appear to play an important role in the precipitation of sedimentary apatite. When sulfide-oxidizing bacteria are exposed to sulfidic and/or anoxic conditions, they hydrolyze their polyphosphate stores, likely deriving energy for metabolism under the anoxic or sulfidic conditions. Laboratory experiments show that the hydrolysis of polyphosphate by these bacteria is sufficient to explain pore water phosphate enrichments observed in sediments where apatite minerals are precipitating in close proximity to mats of sulfide-oxidizing bacteria. Additionally, radioisotope-labeling studies show a link between the polyphosphate in the cells and apatite precipitation in the surrounding sediments.

So, large sulfide-oxidizing bacteria appear to be important for the formation of apatite in modern sediments. But interestingly, our research group has recently observed a similar release of phosphate in response to sulfide exposure from methane seep sediments collected with the remotely-operated vehicle (ROV) Jason from 5000 meter water depths off of Barbados (Figure 1B). These sediments were found to contain vacuolate sulfide-oxidizing bacteria, but these sediments are not known to host the precipitation of apatite. So perhaps there is more to the story of apatite precipitation and phosphorite formation than just the concentration and pulsed release of phosphate from polyphosphate-accumulating giant microbes? To further complicate the story, we also observed a substantial phosphate release from sulfidic sediments in the Santa Barbara Basin off of Southern California. Sediments from the Santa Barbara Basin often contain large sulfide-oxidizing bacteria, but the specific sediments we sampled did not host these bacteria. So where did the observed phosphate release come from? Smaller, less obvious bacteria are also known to store polyphosphate, and perhaps these organisms are responsible for the observed phosphate release. Our group is investigating this hypothesis, in part by looking at the expression of genes that regulate polyphosphate metabolism under various geochemical conditions via a process known as metatranscriptomics. We hope to learn more about this process in the near future.

We are also interested in the formation of phosphorites over geological time scales. We have identified fossilized cells in ancient phosphorites that may represent the mineralized remains of sulfide-oxidizing bacteria. The taxonomic identification of some of these structures remains equivocal because reliance on morphologic features can be misleading. However, in other fossilized bacteria preserved in phosphorites, we have identified geochemical signatures that we suggest are diagnostic of sulfide-oxidizing bacteria. The oldest of these microfossils occur in 600 million year old phosphorites. This period of geologic time, the Neoproterozoic, is known for an unprecedented explosion in the occurrence of mineable phosphorites on nearly every continent. Neoproterozoic rocks also show evidence for the widespread oxygenation of the oceans, as opposed to the atmosphere, which is thought to have become oxygenated in Paleoproterozoic times. Because sulfide-oxidizing bacteria require access to oxygen, or oxygen-dependent chemical species such as nitrate, the correlation between phosphate precipitation and the spread of oxygen in the Neoproterozoic, may be explained by the expansion of conditions that harbor polyphosphate-accumulating bacteria. However, the observations that we have recently made in modern sediments suggest that the
story may be much more complex than we first imagined, and clearly much remains to be investigated.

These studies have the potential to help us better understand the origins of those ancient phosphorites that we use to support modern agriculture. But also, if we can discover the mechanisms by which these bacteria sequester phosphorus in mineral form, we may well be able to better manage dwindling phosphorus resources in the future. New discoveries, new biological and geochemical techniques, and new challenges to the sustainability of our civilization, make this an exciting time to investigate the formation of phosphorites and the microbes associated with them.

**In Memoriam**

**Paul K. Sims**, Sept. 8, 1918-Oct. 29, 2011, received his Bachelors and Masters degrees from the University of Illinois in 1940 and 1942, respectively. In 1950 he completed work for a PhD at Princeton University. After he received his Masters degree, Paul began field studies of ore deposits in Washington and Arizona with the U.S. Geological Survey. After two years in the Navy, Paul rejoined the USGS working on a number of projects including an eight-year study of the geology and ore deposits of the Colorado Front Range. In 1961, Paul was named Director of the Minnesota Geological Survey and concurrently began teaching in the Department of Geology at the University of Minnesota. Under Paul’s leadership the MGS was able to hire the first full-time staff, creating an active, productive organization. Paul continued working in Minnesota for 12 years before returning to the USGS in 1973. He became a member of the branch of Central Mineral Resources and served as project chief for a study of the Precambrian greenstone belts of Minnesota and their regional tectonic framework. In 1980, this highly successful project was expanded to a study, lead by Paul, of Precambrian Tectonics of the Lake Superior region. Paul retired from the USGS in 1995, although he remained active in research and continued publishing scientific papers through 2005. Throughout his career Paul received numerous honors and awards, including the S.S. Goldich Medal of the Institute on Lake Superior Geology (1985), the Ralph W. Marsden Medal of the Society of Economic Geologists (1989), the Department of Interior’s Meritorious Service Award (1984) and Distinguished Service Award (1991).

**Professor Emeritus Glenn B. Morey** passed away Aug. 2, 2012. GB or Morey, as he was called by family and friends, was born in Duluth, MN Oct. 17, 1935. He received his BA in Geology in 1957 from the University of Minnesota-Duluth, his MS in 1960 and PhD in 1965 from the Department of Geology and Geophysics working with Fred Swain. Morey joined the MGS in 1965, becoming its Associate Director in 1976. He was named the survey’s Chief Geologist in 1985 and became a full professor in the Department in 1987. During his distinguished 36-year career with the Minnesota Geological Survey, he played a pivotal role in enabling the MGS to fulfill its mission. In 1972, Morey and P.K. Sims edited *Geology of Minnesota: A Centennial Volume*. Morey retired in 2001 and remained active working on a biography of Newton Horace Winchell, first director of the Minnesota Geological Survey, and a history of the Survey. In 1986, Morey received the S.S. Goldich Medal of the Institute of Lake Superior Geology in recognition of his numerous contributions in geology which included field studies, integration of the geology of Minnesota into the new paradigm of plate tectonics, presentations at regional, national, and international meetings, and in the publications of the Minnesota Geological Survey and national and international professional journals. He was a Fellow of the Geological Society of America and recognized authority on the geology of Precambrian Iron Formations.

Jake Bailey collecting and processing sediment cores from the Santa Barbara Basin on board the ROV New Horizon.
Greetings from the Chair—continued from page 2

and yet these people and labs are essential to our research, teaching, and service mission. We have yet to find a good solution to this problem, given the high level of need across much of the department. Your donations to the department’s general fund provide some help with this important need.

As spring slowly approaches, there will be a number of interesting events in our department, including a career panel for students (featuring alumni and others from various industries and government agencies that employ geoscientists); and the usual spring field trip, this year to the desert Southwest (including Death Valley). By reading this newsletter, you will get a glimpse of some of the goings-on in the department. If you want to keep up with all the geonews from Pillsbury Hall, you can read weekly updates in the news column of our department webpage (http://www.esci.umn.edu/) and/or check out our Facebook page (http://www.facebook.com/groups/81943157076).

I hope that you will enjoy reading this newsletter. As always, I welcome comments, questions, suggestions, and news from alumni and friends of the department.

Subir Banerjee

Varanasi Rama Murthy (1933-2012)

Rama Murthy passed away in California on October 12, 2012 after a prolonged illness. He was 79. On December 20, 2012, students, faculty and researchers from our department, others from across the university, and friends and family of Rama gathered at the Campus Club in Coffman Union to remember him. There was both sadness and joy, gravity and levity, throughout the evening, just as Rama would combine serious science and humorous stories when he would be chatting with students and colleagues in the department or at a conference. People talk of ‘footprints’ and Rama has left behind many large footprints on diverse ‘stages’ where scholarship and pedagogy have played major roles, be it in the U.S., Europe or India.

Our departmental website describes Rama’s contributions in the world of scientific research and academic scholarship. Here perhaps it is more appropriate to draw attention to his roles in leading the department and the School of Earth Sciences, as well as serving the College as Associate Dean and the University as Associate Vice President.

Rama came from the not-too-wealthy village of Anantapur in Andhra Pradesh in India, studied first at Andhra University in Waltair, and then at the Indian School of Mines, Dhanbad where he was the gold medalist (top of class). He met in Dhanbad a visitor, the late Professor Alan Bateman of Yale, and later, armed with a Tata family scholarship, joined Professor Bateman in Yale and got his Ph.D. there. Rama never forgot the struggle he had to wage on the way to academic success, and perhaps that is why he took a personal interest in encouraging students to dream of climbing the apparently difficult ‘peaks’ of scholarship.

In a way, he did the same kind of urging and cheerleading for the department, persuading exceptional young faculty to join the department and then making every effort to support them in achieving their dreams. Rama never missed a chance to let geology alums and faculty of other departments, as well as members of the administration, know of the latest successes of our faculty and students, be it in publishing or reading high impact papers, receiving large research grants, or garnering honors from academic societies. As Associate Dean and Associate Vice-president, he helped faculty of our own and many other departments in their search for ‘matching funds’ for their grant applications. He was also known to be the person to go to when departments wanted to make spousal hires of faculty via the mechanism of temporary funding from the college and university. In particular, Rama was extremely supportive of women graduate students and women faculty, and he and his wife Janice Noruk have left a permanent ‘footprint’ by establishing graduate fellowships in the department, one for the most qualified student, male or female, and the other only for exceptional women graduate students.

It was fun to be with Rama at a conference, at a party or at his home because at one moment he would be talking of basaltic volcanism on the Moon or his conviction that there is sulfur in the Earth’s core, and the next he would be gravely telling us that the most critical step in cooking a pot of perfectly cooked rice is not in the boiling of water but the crucial ‘steaming’ of the nearly cooked rice when the heat has been turned off. And of course, he was an accomplished raconteur from whom we learnt about his hosting at home the world famous musician Ravi Shankar, or the partial credit he took for nominating Gabriel Garcia Marquez for the Nobel Prize in literature which, of course, Marquez won.

I could not be at the GSA meeting in Minneapolis in October, 2011, but I heard how in spite of his poor health, Rama was again the soul of ‘the party’ and the person to whom all the ex-students present came to express their gratitude and respect as well as their love. And those were probably Rama’s most desired things in life.

Subir Banerjee

Donna L. Whitney

Head, N.H. Winchell School of Earth Sciences
Distinguished McKnight University Professor
Honors and Awards

Jake Bailey received an NSF Faculty Early Career Development (CAREER) Award, which supports junior faculty who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research within the context of the mission of their organizations.

Larry Edwards was elected as a National Academy of Sciences Fellow in 2011. The department is honored to have three NAS Fellows among the faculty, Larry, David Kohlstedt (2009) and Herb Wright (1977).

The National Academy of Sciences selected Larry Edwards to receive the prestigious Arthur L. Day Prize and Lectureship honoring his scientific contributions to the study of the physics of the Earth. Larry is only the 14th recipient of the Day Prize since its inception in 1972 and the first from the University of Minnesota. He is best known for his development of extremely precise methods for measuring the ages of rocks, using these methods to date rocks found in caves in China to document climate change patterns in history.

The American Associate for the Advancement of Science (AAAS) selected Larry Edwards and David Kohlstedt as 2012 AAAS Fellows.

Our two junior faculty members, Josh Feinberg and Jake Bailey, were awarded McKnight Land-Grant Professorships for 2012-14 and 2013-15, respectively. This program is designed to strengthen University of Minnesota faculty members for the future and to advance the careers of the University’s most promising junior faculty members.

Marc Hirschmann, Tom Johnson (UofM-Duluth), and Bill Seyfried were elected as Fellows of AGU in 2011.

Chris Paola was honored by the Geological Society of London with their 2011 Lyell Medal, named for perhaps the 19th Century’s most influential Earth scientist, Sir Charles Lyell. Chris’ research was cited for stretching from the dynamics of bedforms and braided rivers to quantitative understanding of large-scale stratigraphic sequences across entire sedimentary basins; distilling essential simplicity from the rich and complex brew of nature’s complexity. His work has not only been of academic importance – it has also impinged crucially upon petroleum geology, river hydrology and engineering.

Tony Runkel (BS’83), MGS Chief Geologist and Adjunct Professor, has appeared on TPT’s Almanac at the Capital and other news reports explaining the value of Minnesota’s sand for the hot topic process of ‘fracking’.

Martin Saar was named a 2011 Institute on the Environment Fellow. The University’s IonE pursues research-based solutions to global grand challenges in five key areas: energy, food and land use, freshwater, population and development, and whole systems. Also in 2011 Martin received the College of Science and Engineering Career Development Award in recognition of exceptional contributions to teaching by a candidate for tenure. Martin was successfully promoted to Associate Professor with tenure.

Donna Whitney and Marc Hirschmann were selected as Distinguished McKnight University Professors, in 2010 and 2011 respectively. These professorships are elected based on the level of distinction their scholarly work brings to the
university; the merit of their achievements and the potential for greater attainment in the field; the dimension of their national or international reputation; the extent to which their intellectual work and reputation are identified with Minnesota; the quality of their teaching and advising; and their contributions to the broader community.

Robert Johnson (Adjunct Professor) and Janey Westin published in 2012 *The Last Kings of Norse-America – Runestone Keys to a Lost Empire*.

Olga Zoltai received the 2012 Immigrant of Distinction Award from the Minnesota/Dakotas Chapter of the American Immigration Lawyers Association. The award honors immigrants who have made substantial contributions to their communities or professions through exceptional leadership, high achievement, or moral courage. Olga exemplifies how treating immigrants with dignity strengthens our moral fabric and brings our country great financial benefits.

**NSF Graduate Fellowships:**
- Brandi Cron, Advisor: Brandy Toner
- Katherine Fornash, Advisors: Christian Teyssier and Donna Whitney
- Laura Vietti, Advisors: David Fox, Ray Rogers, and Jake Bailey

**Graduate School Fellowships:**
- 2010-11 Chris Crosby
- Roxanne Renedo
- 2011-12 Katherine Fornash
- Christie Villanueva
- 2012-13 Giselle Conde

**Graduate School Doctoral Dissertation Fellowships:**
- 2010-11 Amanda Dillman
- Andrew Luhmann
- Jimmy Randolph
- Brooke White
- 2011-12 Dylan Blummetritt
- Ben Stanley
- 2012-13 Anna Lindquist

Antoinette Abeyta, PhD student working with Chris Paola, received an Outstanding Student Paper Award at the Fall 2012 AGU meeting.

Chris Spencer, PhD candidate working with Dave Yuen, received an NSF Summer Fellowship to work in Beijing on cyber-infrastructure.

Three Outstanding Service Awards were made to departmental support staff in 2012. **Mark Griffith**, departmental machinist and Pillsbury Hall manager, beyond his normal duties, worked hard to ensure renovations needed to accommodate the new XRCT were done in a timely and efficient manner. There were many unforeseen problems associated with the installation. Mark’s concern went even as far as having foam protective layers placed in the rock cabinets to keep the samples safe during their move in and out of the hallway in preparation for the big move-in day. **Sharon Kressler**, our student services specialist, always goes well above and beyond her job duties assisting students and faculty alike, especially challenging now in light of the changes in procedures and official requirements brought on by the closing of the Graduate School. **Kathy Ohler**, our departmental administrator, makes sure everything functions smoothly in the department in assisting the head and the faculty. Her hard-earned knowledge of how the University works helps ensure things get done properly and efficiently. One of her many skills is putting the newsletter together in a highly professional manner. Kathy and Sharon together make a formidable pair. They were absolutely key in making the GSA Dinner in October 2011 such a success. The slide show Sharon put together for the event can still be viewed on our department website.

**Birthday celebrations:**
- Dave Yuen celebrated his 63rd birthday while in China and Olaf Pfannkuch marked his 80th birthday with friends and colleagues in the Winchell Reading Room.
Department of Earth Sciences 2012-13

Fall departmental picnic 2012

Departmental research groups and centers are fortunate to attract outstanding postdoctoral fellows and researchers. Below is a list of the most recent additions to these research teams:

**Aqueous Geochemistry Research Group**
Andrew Luhmann – Postdoctoral Fellow  
Chunyang Tan – Postdoctoral Fellow  
Shijun Wu – Postdoctoral Fellow (2011-12)

**Bailey Geobiology Lab**  
Beverly Flood – Postdoctoral Fellow  
Ben Harrison – Center for Dark Energy Biosphere Investigations (C-DEBI) Fellow  
Dan Jones – Agouron Institute Fellow

**Experimental Petrology Research Group**
Lora Armstrong – Postdoctoral Fellow  
Anja Rosenthal – Postdoctoral Fellow (2010-11)  
Paola Ardai– Postdoctoral Fellow (2009-11)

**Geofluids Research Group**
Po-Hao Kao – Postdoctoral Fellow (2009-11)  
Kong Xiang Zhao – Postdoctoral Fellow  
Jimmy Randolph – Postdoctoral Fellow  
Stuart Walsh – Postdoctoral Fellow (2006-11)  
Matt Covington – Postdoctoral Fellow (2008-10)

**Polar Geospatial Center**  
Jonathan Pundzack – Center Manager

**Institute for Rock Magnetism (IRM)**
Dario Bilarrello – Research Associate  
Julie Bowles – Research Associate (2007-12)  
Max Brown – Postdoctoral Fellow (2008-11)  
Ioan Lascu – Postdoctoral Fellow  
Nick Swanson-Hysell – NSF Postdoctoral Fellow

**Minnesota Isotope Group**
Ahmed Al Mikhlafi – Fulbright Postdoctoral Fellow  
Audrey Bouvier – Research Associate  
Yanbin Lu – Postdoctoral Fellow  
Ian Orland – NSF Postdoctoral Fellow  
Julie Retrum – NSF Postdoctoral Fellow  
Anja Rosenthal – Postdoctoral Fellow (2011-12)  
Xunlin Yang – Visiting Research Scholar

**Rock and Mineral Physics Lab**
Miki Tasaka – Postdoctoral Fellow  
Matej Pec – Postdoctoral Fellow  
Janelle Homburg – Postdoctoral Fellow  
Ayako Suzuki – Research Associate (2008-12)

**Structure Tectonics and Metamorphic Petrology Research Group (STAMP)**
Côme Lefebvre – Postdoctoral Fellow  
Maud Meijers – Postdoctoral Fellow

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<td>Research and Teaching Faculty</td>
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<td>Undergraduate Majors</td>
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In March 2012 the department purchased an X5000 high resolution X-ray Computed Tomography (XRCT) system. The new facility was funded in part by a grant to Donna Whitney from the University of Minnesota’s Infrastructure Investment Initiative. The XRCT lab is available for use by researchers within and beyond the University of Minnesota as well as from industry and government agencies. Analyses can be performed by lab staff or by users, including graduate and undergraduate students, who can be trained to operate the equipment and software independently. Brian Bagley, PhD 2011, was hired to manage the new facility and arrived in May 2012. Research from the lab has already been presented at three conferences and we are looking forward to a busy and productive year. See xraylab.esci.umn.edu for additional information.

New Lab Managers: X-ray Computed Tomography Lab ....

In October 2012, Dr. Anette von der Handt joined us to take over the responsibility for the Electron Microprobe Lab. She has more than 10 years of experience in microbeam analysis and has worked with various electron microprobe models on a wide array of applications. Dr. von der Handt got her PhD from the Max-Planck Institute of Chemistry in Mainz working on melt-rock reaction and cooling processes in abyssal peridotites. Since then she has worked on a variety of applications using the electron microprobe and is looking forward to continuing the lab’s excellent service for our internal and external users. More information on the lab can be found at http://probelab.esci.umn.edu.

...Electron Microprobe Lab
Imagine a gentle surf lapping up along a black sand beach just 50 feet from your tent, backed up by coconut palms and remnants of an ancient wall of aa basalt, and you will have a good image of our campsite. It was the second night of the 2012 undergrad field trip to the Big Island of Hawaii. After a long day of hiking over glassy pahoehoe and exploring old lava tubes, we arrived at Ho’okena Beach just south of Captain Cook on the western side of the island. It was nearly dark, of course, but that didn’t dampen the enthusiasm for much needed re-hydration and pitching in to fix dinner. There were no recorded complaints after a great meal of adult macaroni and cheese and broccoli-grape salad, and no complaints about sleeping on a sandy beach.

Those of you now reading this newsletter and who have been on any of Jim Stout’s previous Hawaii trips (2006, 2000, 1996, 1992, 1990, etc.) will probably recognize the Ho’okena campsite as a new one for this trip. Our first campsite, Spencer Beach County Park, is one you will all remember. It’s just north of Hapuna Beach, the one with the great body surfing and the high-end hotels. This campsite has become so popular that we could only reserve the night of our arrival and the night before our departure a week later. That worked out fine; everyone got fed and even had a midnight (body time) swim before crashing.

We continued our counter-clockwise route around the island on the third day, driving down to South Point and hiking the three miles out to the fabled green sand beach. Everyone was so excited about the destination and a dip into the clear waters of this secluded cove that they failed to recognize that the green olivine grains are totally absent from the pyroclastic layers that surround the cove. What is the origin of the green sand beach? Once everyone was out of the water, it didn’t take long to recognize that the green sand was aolean, dropped in by the wind on the lee sides of coves and ledges. Sedimentary processes had their day, but so did olivine crystallization and binary liquidus diagrams!

We spent our third night at Punalu’u County Park along the SE coast in preparation for our morning drive into Volcanoes National Park. An eerie glow beneath the cloud cover to the north had everyone’s attention that evening. After many years of inactivity, Kilauea crater has awakened, erupting gas and pyroclastics non-stop since the beginning of the year. The volcanic hazard was enough for the Park Service to close the paved road around the SE side of the crater rim.

The next day left no doubt as to the level of activity. After a morning of lava tubes, pit craters, tree molds, Pele’s Hair and reticulite, we met with Matt Patrick, a volcanologist at the Hawaii Volcano Observatory (HVO). Matt gave us a tour of the facility and instrumentation used to monitor the recent activity. We also made final plans to meet him the following morning to do some useful work. We would accompany him and a colleague on a long...
hike along the coast to an active lava tube break-out. With a little luck, everyone would have an opportunity to sample fresh, hot basalt from the Pu‘u ‘O’o vent. Later that evening the glow of Kilauea’s eruption from our campsite was enough to motivate a small group to hike over to the rim for a spectacular night view.

The next morning was not disappointing. Everyone was keenly aware of the heat on the hike in as the sun beat down on the jet black lava flows. It didn’t help that long pants, long-sleeved shirt, gloves and boots were required by HVO. Then it really started to get hot as we approached the first of many breakouts of pahoehoe. Sampling and photography is tricky business in this environment. Eyebrows and boards can get singed in a moment if you forget that the object of your photography is moving towards you. For many, this was the highlight of the trip. Everyone had an opportunity to plunge a rock hammer into a molten flow at 1100°C to collect a sample of brand new Planet Earth. Some good science was done as well as several cameras were set up to record pahoehoe inflation in 3-D. More than one of the undergrads was impressed that you can actually get paid to do this kind of work.

After a damp night in the park, we headed for the summit of Mauna Kea and a visit to the Keck Observatory at 13,800 feet elevation. An alkali basalt cinder cone on the way was explored for xenoliths of various types. All are found as cores of bombs that were hurled out of the cone about 5,000 years ago. Some nice dunites, lherzolites and even gabbros convinced the group that these types derived from magma chamber crystallization rather than deeper mantle depths. The summit was impressive, both for the array of telescopes and also for the view: Mauna Loa to the south, Maui to the north, sunshine to the west, and clouds and rain to the east where we were about to descend.

On our sixth day we did the long drive around the north side of the island. Akaka Falls was a required stop, of course, but the day’s objective seemed mainly to get back over to the dry side of the island and everyone’s favorite campsite at Spencer Beach. The following morning the Geo Club treated everyone to breakfast at the Hawaiian Style Café in Waimea. No reservations, cash only, and a quantity of food at great prices that won’t disappoint. It’s a “must stop” for any of you who may find your way back there.

So in summary, it was a great field trip and a great group of undergrads. For Lissa Bardal, Kelsey Blazer, Darren Cheah, Ben Harkins, Alexis Iverson, Rachel Kane, Stephanie Mayer, Mark Neumeyer, Caitlin Olejniczak, Mathieu Pythoud, Katy Rempfert, Alex Seeling, Courtney Sprain, Leif Tokle, Kelsi Ustipak and Nurbeh Yessetov, my thanks for being such great students and for pitching in with the day-to-day camping chores that made this such a memorable trip. Special thanks to Steph for some of the photos.

And as a closing note, my thanks also to all of the students from years past who have been on my field trips to lots of different places and who have helped make every one of them a success. The time has come, however, for me to move on so it is with some reluctance to admit that Hawaii 2012 was the last big trip for me. They have all been great!

Aloha,
Jim Stout

James H. Stout Retirement Celebration
Wednesday, May 15, 2013
University of Minnesota Campus Club
Social hour begins at 5:30 pm

Please join the Department of Earth Sciences in celebrating James H. Stout’s forty-one years of outstanding teaching, research, and professional service at the University of Minnesota. You are cordially invited to a retirement celebration where we will gather to share good food, fond memories, a few testimonials, a humorous story or two, and images of Jim’s illustrious career.

Also consider contributing your stories, photos, and memories of Jim’s impact on your career and life to be included in a book of memories and well wishes we are gathering to present to Jim.

Dinner at the Campus Club $25/person, discount for students
Reservations by May 8, 2013 (contact Kathy Ohler, 612-624-9031 or k-ohler@umn.edu)
Mineral Collection Database

Department’s Mineral Collection Database
(http://mineral.esci.umn.edu)
by Josh Feinberg

“Mineralogy” was the first course I ever taught in our Department, and I remember scrambling immediately before each lecture to find helpful mineral samples that would allow students to get an up-close-and-personal view of the materials that make up our Earth. The main target of my rummaging was the Department’s underappreciated mineral collection, comprising over 7000 specimens, many of which are museum quality. Prof. Newton H. Winchell started the collection in the 1850s shortly after the founding of the University itself. Many of the specimens come from pioneering mineralogists such as Winchell, George F. Kunz, and Tibor Zoltai. A small fraction of the most eye-catching samples are on public display within Pillsbury Hall, but until recently the vast majority of the collection was housed in locked metal cabinets, which meant that the collection received very little use by students and researchers.

Thanks to the organizational efforts of two preternaturally gifted undergraduates, Eric Burdette and Miriam Clayton, the Department’s mineral collection can now be browsed online (http://mineral.esci.umn.edu). This database-driven website improves the visibility and accessibility of our mineral collection and is one of the more extensive of its kind. The searchable, online database contains high-resolution photographs of many of specimens in the University’s mineral collection and provides access to the complete collection. We’re hoping that this website will be expanded to serve as a tool for teaching and research. Educators can link numerous specimens to create online “collections” that emphasize particular themes, e.g., economic mineralogy, common mineral donors, or common geographic origin, and the online database has already been interwoven into courses for Earth Science majors and non-majors. Researchers are able to explore the collection for mineral standards for instrument calibration or more involved experimental research. Further, the online library allows graduate students and faculty to “check out” certain mineral specimens for research, which will let us track the use of the collection for the first time.

Much work remains to be done for Department’s Mineral Collection. There are certain minerals that are poorly represented in the collection and we hope to fill these gaps in the coming years. Undergraduate interns are in the process of systematically photographing each of the mineral specimens for inclusion in the Online Library. Additionally, we hope that the online Mineral Library may serve as a centerpiece for a larger effort to build an electronic mineral library that incorporates mineral collections from a multitude of U.S. educational institutions. By inviting other educational institutions to incorporate their own mineral collections into the database, the value and scientific breadth of the Library will continue to grow well into the future.
The Minnesota Geological Survey (MGS) has released a new State Bedrock Geologic Map. It is only the 8th such state-wide depiction of bedrock geology to be published in the 141 years since inception of the MGS in 1872. Creation of the map “stood on the shoulders” of prior iterations to present new results from a decade of work by scientists from the MGS and other institutions. The map conveys a new level of insight into the rocks that form our landscape, that record evolution of the earth’s crust, and that supply much of our water and mineral resources. The state-wide geologic map serves several important functions. First, it represents a status report of our current understanding of the State’s geology. Secondly, it provides a broad context within which to interpret detailed maps where they exist. And finally, it provides a jumping off point to direct future scientific and resource evaluations.

The map was constructed by six geologists and a number of GIS staff over a period of 3 years. Funding was provided by the Minnesota Legislature, administered by the Minerals Coordinating Committee, and by the State Special Appropriation to the MGS. Crucial to the new level of detail was comprehensive information compiled in the state water well database, and surveys based on rock magnetism and density. Both data sets allow geologists to image the crust beneath younger layers of rock and sediment. Because detailed maps of all parts of Minnesota have not yet been published, this compilation presents the most accurate depiction available for some areas of the state. Computer files that accompany the map allow the user to lift off younger layers of rock to reveal what is inferred to lie beneath, which adds 30% more geologic interpretation than on previous iterations. Corresponding GIS data tables permit attribute searches based on age, terrane, and lithologic and nomenclatural subdivisions. Ancillary files, published as MGS Open-File Report OF10-02, include new state-wide databases and maps of outcrops, bedrock topography, depth to bedrock, and geochronologic data.

The map reference number is S-21, a part of the Minnesota Geological Survey’s State Map Series. It can be viewed on the MGS web site (www.mngs.umn.edu), and prints (size: 4 feet X 5 feet) can be ordered there as well. A companion map, S-22, is a digital-only and print-on-demand version showing Precambrian geology. For more information, contact:

Map Sales Department of the Minnesota Geological Survey; 612-627-4780, ext. 238

Mark Jirsa, Geologist and lead compiler of the maps, Minnesota Geological Survey, College of Science and Engineering, University of Minnesota, 612-627-4780, ext 208 or jirsa001@umn.edu.

Original 1872 geological map of Minnesota by N.H. Winchell (left) contrasted with the 2011 bedrock geology map (S-21) on right.
We wish to express our gratitude to alumni and friends who continue supporting the department with generous donations. Your financial support provides scholarships and fellowships enabling students to carry out their studies, conduct field and analytical research, and present papers at professional meetings. Listed on these pages are gifts received from October 2010 through January 2013. Many of those listed here have given multiple donations.

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Fellowship and scholarship support has grown significantly over the last decade because of our alumni. Your generosity has been the tipping point in many cases, where better financial packages enable us to attract the best undergraduate and graduate students to the University of Minnesota and to the department.

Allan and Eleanor Martini Fellowship

Allan Martini graduated from the University with a B.S. in Geological Engineering in 1951. He started his successful career with Standard Oil of California (now Chevron Corporation) rising through the ranks to become Director of Chevron Corporation and Vice President of Worldwide Exploration and Production in 1986. Throughout his career, Allan was instrumental in Chevron’s worldwide oil and gas operations including oil-field technology and research, and pivotal for the opening international doors in this global market. He received the Outstanding Achievement Award of the University of Minnesota in 2011. He attributes much of his success to the quality of education and training he received in the Department of Earth Sciences. Allan and Eleanor established this fellowship with the hope it would assist others in obtaining the education they will need to find satisfaction and fulfillment in their own careers in earth sciences, giving extra consideration to students expecting to pursue their careers in industry. The department was pleased to award the first Allan and Eleanor Martini Fellowship to Matt Carter for 2012-13.

Robert and Carol Gunn Professorship

Alumnus Robert Gunn and his wife Carol have made a most generous donation of $1,000,000 to establish the Robert and Carol Gunn Professorship for Earth Sciences. The holder of the professorship will be a faculty member in our department with demonstrated excellence in research or outstanding potential. The first holder of the professorship will be selected later this year. Bob Gunn received his BA degree in geology in 1949. He has had a highly successful career in the oil and gas industry, playing a pioneering role in discovery of oil and gas fields in Texas and elsewhere and founding Gunn Oil Company in Wichita Falls, Texas. He has served as president of the American Association of Petroleum Geologists and received the Sidney Powers award from that society for his outstanding contributions to petroleum geology. He received the Outstanding Achievement Award of the University of Minnesota in 1992. He and Carol have provided exemplary voluntary service to their state and community and have maintained strong interests in and support for education. They have recently made a most generous donation to help expansion of two colleges at Midwestern State University in Wichita Falls.
Did you know that strategic philanthropic investments made by forward-thinking alumni and friends are paying off in the form of academic opportunities for our students, now and in the future? It’s true!

In the most recently completed academic year, more than 170 generous donors contributed nearly $1.2 million to the Department of Earth Sciences in the College of Science and Engineering. These gifts are supporting scholarships and fellowships for current undergraduate and graduate students, as well as providing direct support for faculty, programs, research and outreach.

Our benefactors choose to make their philanthropic investments in the form of pledges and outright gifts, many of which are eligible for matching funds, thus multiplying their positive impact. Still others contribute through deferred giving options, such as charitable annuities and trusts, which can provide both income and tax advantages for the donor.

It is well understood that the financial barriers to earning an advanced, high-quality education can be difficult for students and their families. While the University of Minnesota remains committed to doing its part in keeping college affordable, the formula for success must include philanthropic support. Our students, faculty and researchers are deeply grateful to all who continue to invest in them.

For more information about how you can invest in the students and faculty of the N.H. Winchell School of Earth Sciences, contact our dedicated development officer, Paul DeGeest (612-624-5543 or dege0106@umn.edu).

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Graduate Degrees

Nicholas J. Pester, PhD Geology, November 2012, The role of iron and manganese in elucidating the temperature of subseafloor hydrothermal reactions: Insights from experimental and field data, Advisor: Bill Seyfried

Ahmadreza Malekpour Alamdarie, MS Geology, November 2012, Kinematic and thermochronologic studies of Cordilleran metamorphic complexes (Pioneer, Idaho; North Cascades, Washington), Advisors: Christian Teyssier and Donna Whitney

Benjamin D. Stanley, PhD Geology, August 2012, The role of C-O-H volatiles in the Martian mantle and the production of the Martian atmosphere, Advisor, Marc Hirschmann

Frederick A. Davis, PhD Geology, August, 2012, The role of partial melts of peridotite in the formation of oceanic island basalts, Advisor, Marc Hirschmann

Akhan O. Suleimenov, MS Earth Sciences, August, 2012, Advisor: Calvin Alexander

Raphael Gottardi, PhD Geology, July 2012, Thermomechanics and hydrology of a detachment shear zone, Advisors: Christian Teyssier and Donna Whitney

Stephanie S. Day, PhD Geology, July 2012, Anthropogenically-intensified erosion in incising river systems, Advisors: Karen Gran and Chris Paola

Evan M. Finnes, MS Earth Sciences, June 2012, A rock and paleomagnetic characterization of the Duluth Complex layered series intrusions associated with the Nokomis Deposit in NE Minnesota, Advisor: Joshua Feinberg

Lars N. Hansen, PhD Geophysics, May 2012, Evolution of the viscosity of Earth’s upper mantle: Grain-boundary sliding and the role of microstructure in olivine deformation, Advisor: David Kohlstedt

Chiji J. Ochiagha, MS Geology, December 2011, Advisors: David Fox and Vaughan Voller

Sara E. Moron Polanco, MS Geology, December 2011, Paleo-sol carbon isotope stratigraphy, major oxides and rock magnetic record of climate change across the Paleocene-Eocene boundary in the Bogota Basin, Colombia, Advisor: David Fox

Ioan Lascu, PhD Geology, December 2011, Quantification of magnetic components in sediments with applications in paleoenvironmental studies, Advisors: Subir Banerjee and Emi Ito

Jessica L. Till, PhD Geophysics, October 2011, Magnetic and physical characteristics of magnetite associated with deformation and exsolution, Advisor: Bruce Moskowitz

Melissa A. Berke, PhD Geology, October 2011, Molecular and isotopic records of climate variability and vegetation response in tropical East Africa during the Late Pleistocene and Holocene, Advisor: Tom Johnson

Xiuju Liu, PhD Geology, September 2011, Late Quaternary climate history on the Northeast Tibetan Plateau: Multi-proxy investigation of Lake Qinghai sediments, China, Advisor: Steve Colman and Erik Brown

Peter J. Rose, PhD Geology, August 2011, Paleoclimate and mammal paleoecology during the Paleocene of North America: Insights from stable isotopes, Advisor: David Fox

Jimmy B. Randolph, PhD Geophysics, August, 2011, Coupling geothermal energy capture with carbon dioxide sequestration in natural permeable, porous geologic formations – a novel approach for expanding geothermal energy utilization, Advisor: Martin Saar

Mikaela E. Rough, MS Geology, July 2011, H2 and chlorite production from an olivine-rich gabbroic rock assemblage: A modeling and experimental study at 420C, 500 bars, Advisor: Bill Seyfried

Andrew J. Luhmann, PhD Geology, July 2011, Water temperature as a tracer in karst aquifers, Advisor: Calvin Alexander

Brian C. Bagley, PhD Geophysics, June 2011, Seismic structure of the mantle beneath the Pacific hemisphere, Advisor: Justin Revenaugh

Frederick A. Davis, MS Geology, March 2011, Determination of small melt fraction peridotite partial melts using Re foil melt traps, Advisor: Marc Hirschmann

Elisa Fitz-Diaz, PhD Geology, December 2010, Progressive deformation, fluid flow and water-rock interaction in the Mexican Fold-Thrust Belt, Central Mexico, Advisor: Peter Hudleston

Benjamin F. Hardt, PhD Geology, November 2010, Changes in seasonal precipitation of East Central North America with connections to global climate, Advisor; Larry Edwards

Undergraduate Degrees

BS Geology
Su Yi Chai
Rupert S. Cooper
Christopher M. Gonzales
Aubrey A. Lee
Arthur P. Mordaunt
Lucy H. Mulvey
Stephanie L. Olson, with distinction
Matthew W. Pendleton
Leta M. Schoeller
Anthony R. Singerhouse
Leif E. Tokle
Susanna I. Webb, magna cum laude
Jacob A. Wotczak
Michael S. Zazzera

BS Geophysics
Rupert S. Cooper
Christopher M. Gonzales
Aubrey A. Lee
Stephanie L. Olson, with distinction
Leta M. Schoeller
Susanna I. Webb, magna cum laude
Michael S. Zazzera

BA Geology
Sean T. Sitek

BA Earth Sciences
Melissa A. Bardal
Kelsey J. Blazer

Commencement reception for graduates, their families and friends.
Last summer, a team of Earth Sciences undergraduates and I excavated a partial plesiosaur skeleton weathering out of the Bearpaw Shale (~74 ma) in central Montana. The fossil skeleton was first encountered in the summer of 2011 by a Bureau of Land Management (BLM) employee testing the quality of a remote water reservoir. One of my advisers, Ray Rogers (adjunct professor in the Earth Sciences department), traveled to the site to confirm that it was indeed a plesiosaur skeleton, in what looked like good condition. Since my dissertation research is aimed at understanding the early fossilization process of marine vertebrates, including plesiosaurs, Ray thought the plesiosaur would be an ideal opportunity to study marine fossil bones in situ (in place), and invited me to head an excavation on the skeleton. I eagerly accepted but first had to secure funding to travel to such a remote excavation site (~2000 miles round trip for 3 vehicles). The Department of Earth Sciences came to our rescue by providing the necessary funds to make the expedition a reality.

In early June, 2012 I visited the plesiosaur site to undergo a small reconnaissance excavation. Since this would be my first excavation in the Bearpaw Shale and in such a remote area, I wanted to gain a better idea of what to expect for the main excavation. To get to the site, two BLM employees and I traveled over two hours from the BLM office in Lewistown MT, half of which was on dirt roads. At the end of my visit we uncovered over ten perfectly articulated plesiosaur neck vertebrae, indicating that the rest of the neck was likely still in the ground, hopefully leading to a skull. It was also clear that the majority of the skeleton, everything below the shoulder section, was likely lost due to weathering out of the hill. Nevertheless, the hope of a skull, and the excellent preservation of the neck was enough to warrant a full out expedition.

To put the excavation in geologic context, the Bearpaw Shale is composed primarily of blue shale deposited throughout the last major marine transgression of the Western Interior Seaway during the late Cretaceous, approximately 74 million years ago in the Campanion stage. At this time, the oceans were interpreted to be over 200 meters deep and a variety of marine reptiles, fish, and invertebrates inhabited the water, including plesiosaurs. Plesiosaurs were a marine reptile that, like whales, evolved from a terrestrial ancestor into a fully aquatic lifestyle sometime in the early Jurassic period ~ 200 ma (whales evolved into fully aquatic mammals around 41 ma). The type of plesiosaur we excavated is characterized by having an extremely long neck (~70 vertebrae compared to humans’ 7 vertebrae), a small skull, and four flippers (like a turtle). The Lochness monster hoax was likened to a plesiosaur.

After much preparation, I had assembled a field crew composed of Earth Science undergraduates Joan Feakens, Silvia Ascari, Kelsey Blazer, Mikey Spaulding (Morris campus), and Darren Baun (also UMN Morris). We left early on a Monday morning and arrived at the excavation site by the next day. We started...
the excavation by removing overburden down to the bones and uncovering the extent of the skeleton. This was difficult as the neck appeared to be heading directly into the hill and we had to remove over 8 cubic meters of overburden just to reach the skeleton. Complicating the process more, the neck vertebrae were not oriented in a straight line, but were gently curved which required more overburden removal. After two days, we had nearly exposed most of the plesiosaur skeleton and all we had left to find was the skull. But sadly, after several hours of searching, we couldn’t locate the skull because it had likely detached from the plesiosaur body prior to fossilization due to scavenging or the decomposition process.

Once the skeleton was exposed, we applied plaster jackets to groups of bone to prevent damage post-excavation. To prepare for the plaster jacket, the bones were first isolated and elevated from the surrounding rock material. At this point, field data collection was finished, pictures taken, and the quarry map was completed. Then, in a process similar to fixing a broken human bone, we applied a thin plaster jacket (burlap strips coated in plaster) to the pedestaled bones and allowed the plaster to cure overnight. On the fourth and last day of excavation we separated the jackets (there were 7) by removing the rock material underneath the bones and rolling the jackets off of the pedestal. Lastly, we cleaned up the site, reclaimed the area by filling in the excavation pit with talus material, and transported the plesiosaur bones to Pillsbury Hall. Currently, the bones are in the process of being cleaned and repaired for study and museum curation. Silvia, Joan, and Darren are the primary fossil preparators and to date, they have removed most of the rock and repaired broken bone from 3 of the 7 field jackets.

Although the skull and most post-crania were not found, the shape and number of the neck vertebrae indicate that the skeleton likely belongs to the Elasmosaurus group of the Plesiosaria. Elasmosaurs were one of the largest types of plesiosaurs (~14 m long), generally not thought to swim fast, and likely ate fish, belemnites (squid), and ammonites (like nautiloids). Most elasmosaur fossils are recovered from the Pierre shale in Kansas and Montana specimens are rare. According to Pat Drunkenmiller (marine reptile expert at the University of Alaska, Fairbanks), the specimen we excavated is especially significant because it represents the most complete cervical (neck) section of an elasmosaur from the Bearpaw Shale. Furthermore, the position and orientation of the skeleton in the ground provides new insight about the early decomposition process of marine reptile dead-falls.

Lab-based preparation will continue throughout the school year, and I anticipate starting formal research on the skeleton this summer. Key research questions I plan on addressing are (1) a more detailed taxonomic investigation, (2) characterize the degree of damage on the bone surface and internal histology, and (3) to investigate the composition and significance of the concretion associated with some of the plesiosaur bones. The elasmosaur skeleton will ultimately be curated at the Museum of the Rockies in Bozeman, MT.

Laura Vietti is a PhD candidate working with David Fox, Ray Rogers, and Jake Bailey.
Comments on the U of M Geology Club
by Carl S. Benson (BA 1950/MS 1955)

Here are some comments about the Geology Club and how it inspired students, including me. When I asked one of the graduate students, “How do you become a member?” He said: “Members are those who show up,” and I made a point of showing up from then on.

A special highlight was visits by George Gryc (pronounced Grich), an alumus of our Department (BA 1940/MS 1942, †2008). He joined the USGS in 1943 and worked in the Territory of Alaska on exciting reconnaissance geology in the Arctic. He showed maps of Arctic Alaska in 1947 and 1948, north of the Brooks Range. The maps were blank because geologic mapping had been only done along some of the rivers. Wow! This was pioneering, and he held us spellbound. Students wanted to get involved and many did. In 1949 Ed Sable (BS 1948) recommended me to Irving (Irv) Tailleur, Party Chief of a group going west from Umiat in 1950 to do geologic mapping between the rivers. We used weasels to make camps between the Etivluk and the Utukok Rivers, and mapped directly on tri-metrigon aerial photos taken in 1949. The field season lasted from May to September and it was wonderful.

During the 1946 field season George Gryc led a field party using canvas fold boats down the Chandler River from Chandler Lake to the Colville River and upstream to Umiat. This expedition is described in a book by Charles Metzger: The Silent River: A Pastoral Elegy in the form of a Recollection of Arctic Adventure (ISBN-13: 9780961309404). Metzger was the cook and his well-written book gives a vivid feel for the fieldwork.

The Geology Club was amazing. It helped to make the department seem like a college within the massive U of M. Some of the presentations were spectacular; one was the talk presented by Lester King of South Africa in the fall of 1950. Continental drift was not mainstream at that time, but evidence for large-scale movement was accumulating, and King demonstrated stratigraphic continuity between western South Africa and South America.

He summed up by saying, “In the Northern Hemisphere, when it comes to continental drift, you can take it or leave it; in the Southern Hemisphere we are driven to it!” As he said this, he leaned over the lectern with light from below on his craggy face, goatee, and pop-eyes, and banged his fist on the podium; it was memorable. Several faculty members and a group of students took Professor King out for dinner and extended conversation.

I hope the Geology Club still thrives and acts as “glue” for the department.

*The research was part of the USGS investigation of Naval Petroleum Reserve No. 4 established by President Harding in 1924. NPR-4 was the biggest of the Naval Petroleum Reserves; when World War II started, the Navy wanted to find out what was there. It contracted the USGS to set up the “Navy Oil Unit” which was supported by Navy SeaBees (CBs) in building runways at Barrow, Umiat, and Barter Island. NPR-4 is now National Petroleum Reserve-A (NPR-A).
GeoClub Continues to Thrive
by Katie Rempfert, current GeoClub Vice-President

In 2013 the University of Minnesota GeoClub continues to welcome all students interested in studying the earth sciences. The GeoClub and our undergraduate student lounge still provide a home within the huge university and an opportunity to experience camaraderie, as well as giving us opportunities for unique fieldwork, and to learn from the graduate students and professors within the department. This year, we’ve strived to have a greater community impact by giving presentations to elementary students at science and math nights or in their classrooms. We’ve also become more active within the College of Science and Engineering, which has provided us with grants that will allow us to take a short field trip in the spring, aid in our May field trip, and provide pizza for our meetings—a new luxury we can now afford.

Each May we organize a major field trip lead by a member of the earth sciences faculty. Last year, we went to the Big Island of Hawaii with Professor Jim Stout, studying the lava tubes and active flows on the island (see story on page 10). We also had some fun “sedimentary studies”. This May, we will be heading to Death Valley, California and Flagstaff, Arizona to study tectonics, volcanics, and sedimentary features with Adjunct Professor Annia Fayon. We are currently fund raising for this trip through bake sales, a chili cook-off, and a department raffle. In addition the department provides funding for these May trips from the Field Experience Endowment Fund. New this year are plans for a joint trip with the Society of Mining, Metallurgy, and Exploration once the snow melts.

We hope we are living up to the wonderful legacy GeoClub has had in the past!

GeoClub held a fund-raising event this fall that brought together members of the department for a soup and bread cook-off. Students, faculty and staff competed, ate, and enjoyed!
Bruce Doe, EM 1954, celebrated his 80th birthday with a tour of western Canada, including Lake Louise, Banff, Jasper, and Glacier National Park. It was 2 summers of camping in Glacier National Park in 1949 and 1950 with Gary Ernst, MS 1955, that eventually got him interested in studying geology.

Eldon Nahrin, BS 1969, is the asbestos division manager for Custom Environmental Services, Inc. in Arvada CO.

Noel Potter, PhD 1969, shared this story:
In exchange for a contribution to our local public radio station, we joined 3 bus loads of folks on a trip to Wolf Trap Performing Arts Center west of Washington to see Garrison Keilor and Prairie Home Companion live. Some 50 or so of us gathered next to the big trailer truck with the red cab saying "Prairie Home Productions" and "Dedicated to Chet Atkins" at the dock. Out came Garrison with red sneakers and putting on his too-long red tie. He’s as funny in person as on the radio, complete with dancing bushy eyebrows and a face seemingly made of rubber. He chatted with our group for about 10 minutes, signed a few autographs, and many cameras clicked. As he was about to leave, I told him that I had spent 6 years in the 1960s in Pillsbury Hall on the University campus. He immediately said, “Ah, Geology,” and exchanged a few words about the architectural treasure Pillsbury is. Then just before leaving to go back inside, he said “You know, the English Department is taking over Pillsbury.”

Robert Rutford, PhD 1969, prior to attending the 2011 GSA meeting in Minneapolis sent his recollection of the last GSA meeting in Minneapolis held in 1972. He was leading a field trip along with Charles Matsch and Merlin Tipton (South Dakota Geol. Survey). They ended the trip at Sam Goldich’s Morton gneiss quarry and served martinis, crackers and cheese. If remembered correctly there were a few martinis served on the bus and all arrived at the Sunday evening party feeling little or no pain! Bob received the 2010 Medal for International Scientific Coordination by the Scientific Committee on Antarctic Research (SCAR). He was recognized for his longtime leadership in international Antarctic research and for “championing and promoting international coordination” in Antarctica for the last 40 years. The award also recognized his vice presidency and presidency of the organization.

Subbaraman Viswanathan, PhD 1971, retired as the Director of the Atomic Minerals Division of the Department of Atomic Energy, Government of India in 1993. During his career he publish fifty research papers, delivered numerous lectures and keynote addresses at national and international conferences. He coauthored “50 Years of the Journal: Some Significant Landmarks” for the Golden Jubilee Celebration of the Geological Society of India in 2008. He discovered basaltic komatiite in the Kolar Gold Field of Indian and peridotitic komatiite in several localities of Karnataka, India. At 79 years old, he stays active publishing research papers on geochemistry of pegmatitic columbite-tantalite, critical element ratio maps of granitic terrains for exploration of atomic minerals, and wavelength-dispersive x-ray fluorescence spectrometry in geochemical analysis.

Dwight Gustafson, BS 1972, retired on December 31, 2012 from Saudi Aramco where he worked as a senior geophysical consultant. He is now living in Northbrook, IL and plans to stay involved in earth sciences through the AAPG, SEG, and GSA.

Mike Mudrey, PhD 1973, retired from the Wisconsin Geological and Natural History Survey in 2005. He received the Goldich Medal in 2006 and continues to be active in numerous fraternal organizations since his retirement.

Kist Saint, PhD 1973, retired from California State University-Fullerton after 32 years of teaching and research.

James Quick, MS 1974, is the associate vice president for research, dean of graduate studies, and professor of earth sciences at Southern Methodist University. He joined SMU after a distinguished twenty-five year scientific career with the United States Geological Survey (USGS). He assumed this newly-created position at the SMU in August 2007 after serving as Program Coordinator for the Volcano Hazards Program with the Survey.


Mark Saporito, MS 1975, has been the Database Manager for Heart of America Northwest since 2009. Heart of America Northwest has spent over twenty years working for the timely cleanup of nuclear waste at the Hanford Nuclear Reservation.

Keith Sverdrup, BS 1975, is a professor of Geophysics at the University of Wisconsin-Milwaukee.

Geoff Delin, BS 1976, worked for two years as a professional geologist for a local engineering consulting firm before beginning his career with USGS. He’s been with USGS for over 32 years, 29 of which were in the Minnesota Water Science Center (WSC) in Mounds View, MN. As a hydrologist with USGS he authored more than 60 peer-reviewed interpretive reports and journal articles and made more than 70 conference presentations. His career benefited greatly from having the privilege of working with many eminent scientists within USGS and academia. His most recent work in Minnesota included being the WSC groundwater specialist, where he was a technical advisor to local scientists, as well as conducting research on groundwater recharge processes and on the fate and transport of petroleum hydrocarbons at the USGS crude-oil spill research site near Bemidji, MN. In 2008 he transferred to the Denver USGS offices to assume the duties of regional groundwater specialist for 15 states within the central part of the country. He was looked upon as a technical resource within the region to ensure that groundwater activities conducted by USGS scientists meet quality standards and programmatic requirements. He reviews WSC data-collection programs, project proposals, groundwater models, groundwater reports, and aquifer tests to assure that proper technical procedures are
being used. In addition to the above responsibilities, he continues to be involved in research at the Bemidji crude-oil spill site. The attached picture was taken in June 2010 in the Swiss Alps, with the Eiger, Mönch, and Jungfrau mountains poking above the clouds in the background. He had just given a presentation on some research from the Bemidji site at a conference in Zürich and afterwards was able to take a little R&R time with his wife in the Alps. “I feel very blessed that my career has helped provide me with a rich and fulfilling life, including a beautiful wife and two wonderful children who are now grown and on their own. That career started with an enriched education at the University of Minnesota, Department of Geology and Geophysics. Many thanks to the faculty and to the institution!”

**Aberra Mogessie**, MS 1976, visited the department and Peter Hudleston in the fall of 2011. Aberra is a professor at the University of Graz in Austria. For his thesis, he worked with Paul Weiblen on Cu-Ni mineralization in the Duluth Complex. He is involved in a new research project studying the origin of platinum in the Duluth Complex, with colleagues from a number of institutions, including NRRI at Duluth. This is what brought him to Minnesota. Peter Hudleston believes Aberra was the first person to discover platinum in these rocks back in the 1970s. It is one of the minerals in which mining companies are currently showing renewed interest. He is originally from Ethiopia and is active in African geology. He is the president of the Geological Society of Africa.

**Donald Jakes**, BS 1977, retired from the Minnesota Pollution Control Agency in 2010, after working in state government for 35 years, 33+ of it with the MPCA.

**Tawn Albinson**, MS 1978, is the Managing Director in Mexico of Baja Mining Corp, and also runs a Fluid Inclusion Laboratory in Mexico City providing consulting services to various companies in the mining industry.


**Eldon Gath**, BS 1978, received the 2010 GSA Burwell Award made to the authors of a published paper of distinction that advances knowledge concerning principles or practice of engineering geology, or of related fields of applied soil or rock mechanics where the role of geology is emphasized.

**Ronald Graber**, MS 1978, is the General Manager – South American Exploration Division for Cliffs. He set up a Cliffs office in Santiago, Chile. Over the last couple of years he has been in routine contact with Jim Miller at UMD as a member of their Precambrian Research Center industrial advisory board and also UMD’s College of Science and Engineering external advisory board. He has built a retirement home in Rochester, MN and will work from a home office for Cliffs once he returns from South America in the next couple of years.

**George Mickelson**, BS 1979 (Geo minor), is retired from the Wisconsin DNR.

**Mike Foster**, MS 1981, is considering retiring after more than 30 years with Exxon. He and **Janet (Miciek Foster)**, BS 1980, continue to enjoy life in Houston.

**Marcia Bjornerud**, BS 1983, received the National Educator of the Year Award from the Association of Women Geoscientists at the national GSA meeting in Minnesota 2010.

**Dana Johnston**, MS 1978/PhD 1983, was appointed in 2010 as Associate Dean of Natural Sciences at the University of Oregon.

**Kimball Forrest**, PhD 1983, was out in the Wrangell mountains and noticed a spectacular fold in the canyon wall. The fold reminded him of Peter Hudleston’s Structural Styles class. Below is a picture that hints at the amazing structures.

**Joe Hartman**, MS 1976/PhD 1984, received the University of North Dakota Chester Fritz Distinguished Professor Award (the highest award a professor can receive from UND).

**John Jaschke**, BS 1984, is the Executive Director of the Minnesota Board of Water and Soil Resources (BWSR).

**Scott Murchie**, MS 1984, is a principal investigator with Compact Reconnaissance Imaging Spectrometer for Mars (CRISM).

**Don Sprowl**, PhD 1985, is the Assistant Provost for Institutional Research and Accreditation at Indiana Wesleyan University.

**Horst Worm**, Postdoc 1986-89, has visited the IRM a number of times since returning to Germany. Horst teaches in Dassel and he and his wife, Kathrin, enjoy country life without being too far away from cities.

**Barry Goldstein**, MS 1980/PhD 1986, is the Director of Environmental Policy and Decision Making Program at the University of Puget Sound. He and Marian spent a sabbatical leave in Spain in the fall of 2011.
Chuck Anderson, BS 1989, left Penn State at the end of December 2012 and moved to Boulder, CO. He is now the Water Column Sonar Data Manager for the NOAA National Geophysical Data Center working through CIRES at CU in Boulder. He and his wife Susie are settling into their new house and are starting to explore all that Boulder has to offer.

Robert Lamons, BS 1983/PhD 1991, retired from teaching, but is busy volunteering with the local mercury museum, working on mercury education for the Los Almaden Creek Watershed, leading wildflower walks, working on a wildflower book, clearing trails for the county parks, helping out at the New Almaden Community Club, helping a neighbor friend with MS, making posters and t-shirt designs, taking pictures of her cat in compromising positions, and making stained glass windows. Robbie has 3 grandchildren living in St. Paul.

Greg Brick, BA 1993, is completing his PhD under the supervision of Calvin Alexander. His book “Subterranean Twin Cities” received the 2010 Heritage Preservation Award of the American Institute of Architects.

Paul Kelso, MS 1990, PhD 1993, received a Michigan Distinguished Professor of the Year Award from the Presidents Council of State Universities of Michigan (PCSUM) in 2011.

Mike Plante, BS 1996, is a senior hydrogeologist with Leggette, Brashears & Graham, Inc., in St. Paul MN.

Rachel (Bursheim) Breckenridge, BS 2000 married Andy Breckenridge, MS 1999. They have a daughter, Stina, and recently moved back to Duluth from Erie, PA and are doing great! Rachel is teaching math and stats at UMD and Andy is teaching geology at Univ. Wisc. Superior. Since graduating Andy and Rachel have been going to school (Rachel: MS math, secondary teaching math; Andy: PhD geology), working (teaching), and travelling. They have gone on several canoe trips to Northern Canada, backpacking trips to the southwest, and went to Norway.

Dan Doctor, PhD 2002, and Katarina are doing well in Reston, Virginia. Dan works for the USGS as a research geologist, mapping quadrangles in the karst environs of the Appalachian Great Valley. In his spare time, he enjoys house, car, and computer maintenance. Katarina is a PhD student in the Dept. of Geography and Geoinformation Science at George Mason University; in her spare time, she flies a Cessna 172.

Nathan Gruman, BS 2004, for the past 7 years, Nathan has been working for Braun Intertec providing environmental consulting services relating to the redevelopment of contaminated properties. Since leaving the U of MN Geology Department, Nathan has successfully passed the Fundamentals of Geology and Professional Geology licensure exam. He is now a licensed professional geologist (PG) with the State of Minnesota. As of early this February, Nathan has also become a licensed monitoring well contractor, which involves designing, supervising the installation, or installing more than 50 monitoring wells and passing an exam regarding the rules and statutes set by the Minnesota Department of Health. Nathan is an active member of the Society of Mining, Metallurgy, and Exploration (SME) and is currently the President of the Minnesota Section of the American Institute of Professional Geologists (AIPG).

Nathan has two children: a girl (7) and a boy (almost 5). He lives in south Minneapolis.

Joel Poppert, BS 2004, is currently enrolled in the Global Energy Management (GEM) Masters in Science Program at the University of Colorado Business School (plans to graduate June 2013). He has owned and operated Rocky Mountain GeoExploration, Inc., dba Alpine Geothermal Drilling since February 2007, which specializes in the installation and design of Geothermal Heating and Cooling heat exchangers a renewable energy technology, and specialized exploratory and environmental drilling/remediation projects. He is the current president of the Colorado Geothermal Energy and Heat Pump Association (CoGEHPA), where he works with developing the geothermal industry, unifying the industry and its stakeholders, educating the public and engaging in public policy. He is currently working with Senator Gail Schwartz of Colorado on a Renewable Thermal Standard (RTS) for the State of Colorado that is being introduced into the 2013 state legislature. The RTS is a pioneering piece of policy that addresses the gaps left out of the state’s renewable portfolio standard by introducing measures to help bring thermal renewable technologies to economies of scale. In October of 2012 he launched another company called Sun Tzu Energy, LLC that is a development firm that organizes and brings finance to clean energy and triple bottom line projects. They are currently working on several pilot projects and if successful will be taking the business plan national very shortly.

In his free time Joel enjoys playing hockey, back country skiing, hiking, relaxing at the local watering hole, and debating global energy strategy and policy.

Ted Scott, PhD 2006, and his family are still living and loving the Pacific NW. He is still working as a software tester for Microsoft, which greatly values his geophysics skills whenever there is an earthquake drill. Ted’s daughter, Miranda, will soon be starting middle school, and plans to attend the U of MN someday (totally her idea!). His wife, Bree, works in the King County Library system, and will soon be adding to the number of advanced degrees in the household. Ted is still racing bicycles and rock climbing, which has become their family sport of choice. “In my spare time, I plan for the next career change - hopefully announced in next year’s alumni note! Good luck to everyone! I miss you all.”

Send Us Your News and Comments

Please send comments on this newsletter, reminiscences of your days at the University of Minnesota, and/or news of your career or family to esci@umn.edu. Your updates could also be sent by using the Alumni News form found at http://www.esci.umn.edu/alumni/contact.html.
Ravi Appana, MS 2009, has been working at Environmental Resources Management (ERM). In addition to the regular hydrogeo duties, he started developing the modeling and visualization capabilities for the India Business Unit. In July 2012 he moved to a city called Bengaluru (previously Bangalore). In addition to being close to his hometown, Bengaluru has perfect weather all through the year (like California). Although it is a cosmopolitan city with people from all around the world, it has a southern Indian touch which he enjoys every bit of it. “All things said, I still miss Minnesota.”

John Quinn, MS 1992/PhD 2009, is with the Environmental Science Division of Argonne National Laboratory. He visited the department this winter and got to hang with Olaf while in town; he also saw Sharon, Scott, Calvin, and Martin briefly. “And I didn’t get hit by the snow off the roof!” John sent these photos—note the “fix” by Facilities Management to the perennial snow avalanche hazards to people as well as vehicles.

Ryan Swanson, BS 2009, received a 2011 NSF Graduate Research Fellowship as a graduate student at Penn State for his research on an electrical-geophysics approach to understand and predict anomalous contaminant transport in groundwater.

Cale Anger, MS 2010, continued his education in the UofM Civil Engineering program. He received an MS in CE in 2012, winning the UofM’s 2012 Distinguished Master’s Thesis Award.

Anna Henderson, PhD 2010, is working for Senator Franken as an AAAS and AGI Congressional Science Fellow. Dan King, PhD 2010, is working at the Department of Energy. Anna and Dan’s 2nd child, Silas, was born on Dec. 23, 2012.

Jessica Till, PhD 2011, participating in Expedition 335 of the Integrated Ocean Drilling Program as a shipboard scientist aboard the drilling research vessel JOIDES Resolution from April 14 - June 3, 2011.

As this newsletter goes to print, LacCore is in the process of moving into Pillsbury Hall and Shepherd Labs. The facility is scheduled to stay in these temporary spaces for eight months to a year while the Civil Engineering building is renovated. LacCore’s 25 staff and technicians are very excited to run into our Earth Sciences colleagues in the halls, and want to thank everyone in advance for your patience with their noise, traffic, and visitors. New Core Lab location: 30 Pillsbury Hall, 612-626-7889 or laccore.org.

20% of the LacCore staff: Anders Noren, Amy Myrbo, Ryan O’Grady, Jessica Heck, and Kristina Brady.
We continue the search for missing alumni and friends. Your help in locating these missing persons would be greatly appreciated. Do you know the whereabouts of...

Missing but not forgotten...

Elmer D. Anderson, BS’1948
John E. Boettcher, BA’1949
James W. Joyce, EM’1949
Clarke R. Lewis, MS’1949
Roy T. Sorenson, EM’1949/MS’1952
Robert W. Timm, EM’1949
Mary E. Lugsdin, BS’1950
William H. Becker, EM’1951
John H. Goodrich, EM’1951
Kenneth H. Johnson, BS’1951
Wayne H. Kelly, BS’1951
Russell A. Nelson, BS’1951
Douglas M. Sheridan, MS’1951
Edward S. Hughes, BS’1952
Gene M. Olson, EM’1952
Howard L. Ellinwood, PhD’1953
Allan Kiliman, BA’1953
Richard P. Maley, PhD’1953
Murray Lloyd Miller, PhD’1953
Eugene L. Palusky, EM’1953
Orville J. Pardau, BS’1953
Charles J. Beaupré, EM’1954
Rudolf R. Moen, EM’1954
Howard W. Blakely, BS’1955

Bernardo A. Taborda, MS’1955
Iwan Tkatchenko, EM’1955
Ashiq Ali, MS’1956
Roy W. Hillmer, EM’1956
Jack D. Arthur, BA’1957
Robert H. Barton, BS’1957
Robert C. Kaase, EM’1958
Leslie G. McDowell, BS’1958
Warren C. Miller, BA’1958
Gary C. Stamman, BA’1959
Reynaldo Ayala, BA’1960
Arthur E. Anderson, BA’1961
John R. Guenther, EM’1961
Conrad E. Maher, BS’1961
Pundalik Kulkarni, MS’1962
Barton D. Gross, MS’1963
Naising Wang, MS’1963
Dennis G. Deischl, MS’1964
Harold A. Johnson, BS’1964
Charles E. Knigge, BA’1967
Jeffrey B. Carruthers, BS’1968
Douglas B. Moore, BA’1968
Jacques Becker, MS’1969
Joel L. Renner, BS’1969
Robert E. Smith, BS’1969
Dale Wikre, BA’1969
Dominique Ray, MS’1971
Richard K. Covill, BS’1972
Sally Wright Kendrick, MS’1972
Douglas O. Phair, BS’1972
John E. Puffer, BS’1972
Sudarshan Singh, MS’1972
Mark Markowitz, MS’1973
Larry D. Douglas, MS’1974
James Carl Engstrom, MS’1974
William Thomas Gill, BS’1974
Bruce H. Burton, MS’1975
William J. Loye, BS’1976
Carolee Berge, BS’1977
Robert G. Bowman, BS’1977
Stephen R. Elkins, MS’1977
Ann Hubbs, BS’1977
Benjamin A. Arogundade, BS’1978
Randall R. Atchinson, BS’1978
Michael Bower, BS’1978
Thomas Geskerman, BS’1978
John A. Miller, BS’1978
Lorene Gergcn, BS’1979
Steven A. Meger, BS’1979
Paul W. Loaney, BS’1980
James Paulson, BS’1980
Dong Jin Kim, MS’1982
Michael A. McCrum, BS’1982
Dora B. Barlaz, MS’1983
Brian A. Ross, BS’1983
Chomgmi Suk, MS’1985
Dongwoo Suk, MS’1985
James E. Doten, BA’1986
Ahmad B. Ibrahim, BS’1986
Kevin E. Miller, BS’1987
Wendy Lynn Tormansen, BA’1987
Joseph G. Kroening, BS’1988
Janice M. Lawhead, Ed’1988
Richard T. Wilkin, BA’1988
Ellen K. Kirschner, BS’1989
Mary J. Lynch, BA’1989
Christopher Manydeeds, BS’1989
R. Jonathan Paetz, MS’1989
Jacqueline Black Jiran, BS’1990
Kurt S. Pfaff, MS’1991
Anbin Yu, BS’1992
Craig L. Kurtz, BS’1993
Jennifer Mackenzie, BS’1993
Elizabeth E. Bembenek, BS’1995
Kriste M. Davenport, BS’1995
Scott Rubin, MS’1995
Sanghamitra Sahu, MS’1995/PhD’1997
Virginia F. Davis, BS’1996
Jon Paul Jones, BS’1996
Susan Ginsberg Hamnn, MS’1997
Gideon Norbert Ngobi, MS’1998
Garrett Mark Kramer, BS’1999
Jennifer York, PhD’2000
Michelle M DiGirolamo, BS’2001
Kelly A. Wheaton, BS’2001/BS’2002
Bilikisu Davies, BS’2002
Nicole R. Elgiehun, BS’2002
Ross D. McNeil, BS’2003
Lily M. Wood, BS’2003
Nicholas R. Bonov, BS’2004
Yongsul Cho, MS’2004
Samantha A. Heck, BA’2004
Travis Charles Kennebeck, BS’2004
Matthew L. Rheinhart, BS’2005
Richard A. Cargill, BS’2006
Djuna Maria Gulliver, BS’2006
Jumun Sh, BS’2009
Su Yi Chai, BS’2011

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