INSIDE

The Mylonite

The Newsletter of the
Geological Sciences Dept.
Calif. State Polytechnic University
Pomona, Calif.
Issue 19
December 2011

NEWS FROM THE CHAIR

Department Overview for 2011

Dear Geology Alumni and Friends: It's already time for another round of the Mylonite. I hope this newsletter reaches all of you in good health as the holiday season approaches. The Geology Department faculty and staff continue to tackle various endeavors and initiatives to promote our teaching and research mission and make the Department a better place to prepare our students for careers. This year we hired a new faculty member in Hydrogeology and put the final touches on our new Master of Science degree program, to be launched in September, 2012. We acquired several new equipment items, including two seismometers, an ion chromatograph and a 12-passenger Ford van, to support our laboratory instruction and fieldtrips. Last May the Department underwent its 5-year Academic Program Review, receiving constructive and complimentary feedback. Several active grants supported faculty research programs, and we have recently been awarded a $1.4 million collaborative grant with Biology to facilitate the successful transfer and retention of students from Pasadena City College. We continue to celebrate our student successes through scholarship awards at the annual alumni reunion and graduation ceremony.

All of these accomplishments required a concerted team effort. Looking back on our last year's highlights I feel very fortunate to be working with such a cohesive and productive group of faculty, staff and students. Described below are a few items of general interest. Please also visit our Geology Department web site at http://geology.csupomona.edu/

I hope you enjoy this 19th edition of our annual newsletter. Before we get started you might enjoy this photo recovered by Dean Srinivas from the College of Science archives. Back then there was no Geology Department at Cal Poly Pomona.

View of Cal Poly Pomona Campus in 1957. Can you find Building 3?

New Assistant Professor in Hydrogeology

The Geology Department is pleased to welcome Assistant Professor Stephen Osborn to our faculty. You can read more about Stephen later in this newsletter. Below are a few notes and a photograph:

Dr. Osborn is a hydrogeologist whose research focuses on the elemental and isotope geochemistry of surface water and groundwater to understand the source of solutes, fluid flow pathways, and biogeochemical processes. He also has expertise in natural gas geochemistry and wa-

ter quality issues related to hydrocarbon migration and extraction. Stephen holds degrees in Environmental Science (BS) and Soil Science (MS) from the University of California at Riverside, Geology (MS) from Georgia State University, and a Ph.D. from the University of Arizona. Between MS degrees, Stephen worked as a consultant for 6 years, conducting hydrogeologic and environmental investigations in the northeast and southwest US, which included phase I and II assessments and remedial feasibility testing. Most recently, Stephen has conducted research in New York and Pennsylvania investigating basin scale fluid flow, water-rock interactions; microbial methane; and the source of fluids and natural gas in groundwater systems.

This year Stephen will teach our Groundwater Geology and Geochemistry courses as well as a Hydrogeology Field Module and Physical Geology Lecture and Laboratory. He is developing additional water-related courses to be implemented with our new Geology Masters degree program next fall (2012). Stephen is currently building an aqueous geochemistry / hydrology laboratory. His startup package included significant equipment purchases. A new Dionex ion chromatograph has already been installed, and a Milli Q Ultra-Pure water purifier has been ordered. These instruments, along with other miscellaneous hardware items and supplies, will enhance the Geology Department's analytical capabilities for water quality studies.

Stephen Osborn pictured on his trip out to Cal Poly Pomona from Duke University last August. Bet you can't guess where this shot was taken.

Graduate Program to Be Launched September 2012

We invite applications for our new Master of Science degree program in Geology, scheduled to begin September 20, 2012. Application period is October 1, 2011 through June 15, 2012. Details of this program, including admission requirements, curriculum and instructional plan for the first three years may be viewed at

http://geology.csupomona.edu/graduate.html

The Program

Our Master's program in Geological Sciences is designed to prepare graduates for employment in all fields of geology, and teaching at secondary and community college levels. Emphasis is placed on applied skills demanded by potential employers. Fundamental to the program is a thorough understanding of basic geologic principles rooted in field and laboratory experiences. The geologic framework provided by the MS degree will enable graduates to meet the intellectual challenges of their professional or academic careers and assume leadership roles in their profession. The program is sufficiently flexible to meet student interests in the application of geology to the solution of hydrologic, geophysical, environmental, geoengineering, or resource extraction problems facing our society. As a polytechnic university we are dedicated to the "Learn by Doing" philosophy and stress practical interactions between students, faculty and industry/ government professionals.

The Geology MS program targets applicants who are 1) seeking to advance careers in a job market where promotion opportunities require a Master's degree, or 2) seeking future entry into competitive PhD programs. Applicants are expected to include alumni of the CPP Geology BS program; CPP Geology seniors; BS graduates from other Universities. As our applicant pool grows, we will be conducting surveys to help plan specific times to offer the graduate courses. Recognizing that our graduate students will have work and family constraints, we want to accommodate as many of these needs as possible. Course scheduling will likely involve afternoon and evening classes with most laboratories and field trips offered on weekends.

How to Apply

Apply online through http://www.csumentor.edu/

For prompt feedback, also send hard copies (or electronic files) of your application and supporting materials to:

Jonathan Nourse, Graduate Coordinator;
janourse@csupomona.edu
Department of Geological Sciences
3801 W. Temple Avenue
California State Polytechnic University
Pomona, CA 91768

New Equipment Purchases

The Geology Department has gained substantial new equipment and laboratory upgrades over the past 3 years through successful external grants and redirection of the Instructional Cost Recovery. Geology participation in the recently funded collaborative grant with Pasadena City College (PCC CPP STEM Pathway) provides $142,000 of additional equipment and supplies during the next 5 years. We are well-prepared to support graduate-level field and

laboratory research with the most current equipment available.

Below is a partial list of significant equipment purchased through various Geology Department enterprises over the past 3 years:

- Seismic refraction surveying equipment with accessories
- Ground-penetrating radar surveying equipment with accessories
- Two Nikon Total-station survey stations with accessories
- Three field-deployable Guralp seismometers
- 12-passenger Ford van to support field trips
- SMART upgrade of AV system in room4-A-634 classroom/laboratory
- Ion chromatograph water quality analyzer
- Hand-held field deployable multi-parameter water quality meter
- Two water velocity flow probes
- Seven hand-held GPS receivers
- Twenty brunton compasses

Here are some photographs to show some of the more recently acquired equipment in action. You may view additional pictures of students using equipment at: http://geology.csupomona.edu/jpolet/Jascha_Polet_at_Cal_Poly_Pomona/Field_Photos.html

GSC 255L campsite in Marble Mountains. Our new 12-passenger Ford E-350 van is on the left, our Ford F-250 crew-cab pickup in the center and Rob Ellis' Nissan on the right. Photo courtesy of Geology student Raymond Ng

Seismometer being retrieved from "vault" on the Big Island of Hawaii

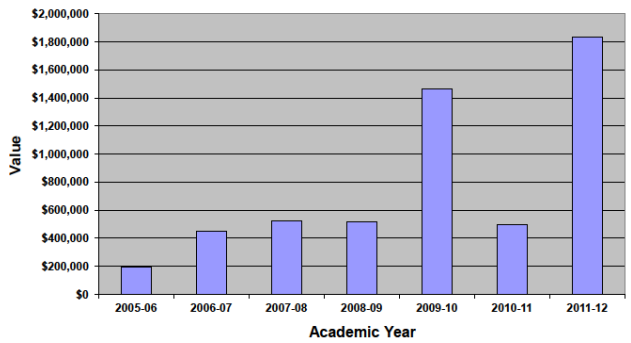
Jennifer Kurashige demonstrates use of the multi-parameter water quality meter

Grants and Contracts

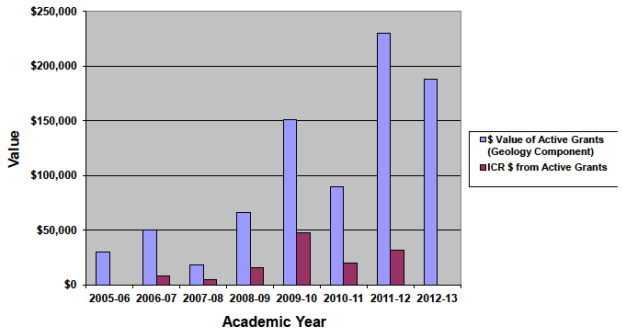
External research funding generated by Geology faculty members is an important and growing component of our resource base, as shown by the charts below. These endeavors will support Master's thesis research and sustain our equipment needs. Recent highlights include:

- **$230,258** in active grants for 2011-12
- **$187,848** projected grant committments known so far for 2012-13
- Recent award of a **$1.4 million** Department of Education collaborative STEM grant with CPP Biology Department to enhance pathways for transfer students from Pasadena City College (see Poly Centric news article): http://polycentric.csupomona.edu/news_stories/2011/11/partner-pcc-stem-grant.html
- Equipment and supply purchases funded by the Department of Education grant total **$190,466 over 5 years**
- **$121,526** equipment proposal submitted by new faculty member Stephen Osborn to the **NSF / MRI program** seeks to purchase an Oxygen-Hydrogen Stable Isotope analyzer to augment Geology Department capabilities in water quality analysis

Dollar Value of Grants Submitted by Geological Sciences Department Faculty: 2005-12



Dollar Value of Active Geological Sciences Department Grants: 2005-12



2010-11Curriculum Changes

Principle changes to our curriculum during 2010-11 involved finalization and official approval of expanded course outlines for the graduate program. Twelve new 500 and 600-level courses were designed, and one new 400-level course, Planetary Geology--GSC 495. We also reworked most of our 400 level courses so that they can count for either undergraduate or graduate credit. Below is a list of these courses:

New Graduate courses:

GSC 501 Advanced Topics in Geosciences (3)
GSC 503L Field Investigations (2)
GSC 534/L Quaternary Geology (3/1)
GSC 541/L Micropaleontology (3/1)
GSC 545/L Advanced Hydrogeology (3/1)
GSC 551/L Petroleum Geology (3/1)
GSC 564/L Advanced Shallow Subsurface Geophysics (3/1)
GSC 568/L Topics in Advanced Seismology (3/1)
GSC 5xx/L Water Quality / Contaminant Transport (to be developed)
GSC 600 Thesis Proposal (1)
GSC 694 Thesis Research (6)
GSC 696 Masters Degree Thesis (3)

Courses that may count for Undergraduate or Graduate credit:

GSC 410 Earth Science Seminar (2)
GSC 411 GIS Applications for Earth and Environmental Scientists II (1/2)
(to be renumbered from GSC 311)
GSC 415/L Engineering Geology II (3/1)
GSC 423/L Sedimentary Geology (3/2)
GSC 424 Igneous and Metamorphic Petrology (3)
GSC 425L Igneous and Metamorphic Petrology Lab (2)
GSC 433/L Ore Deposits (3/1)
GSC 434/L Shallow Subsurface Geophysics (3/1)
GSC 440/L Exploration and Mining Geology (3/1)
GSC 444/L Geotectonics (3/1)
GSC 450/L Introduction to Seismology, Earthquakes and Earth Structure (3/1)
GSC 495 Planetary Geology (4)

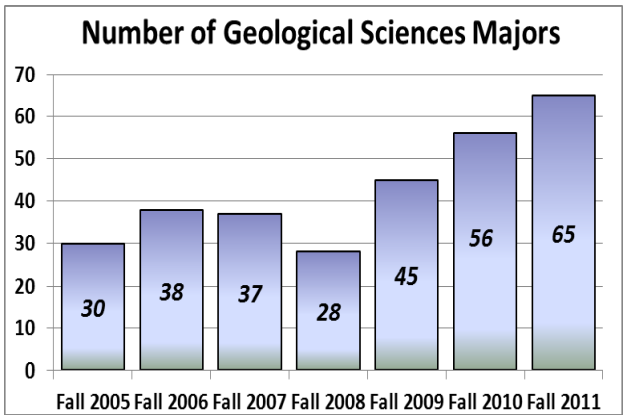
The curriculum as it stands today has sufficient flexibility for students to take certain restricted electives outside their chosen track. We will also be able to add restricted electives to the lists or delete certain courses as we experiment with this program.

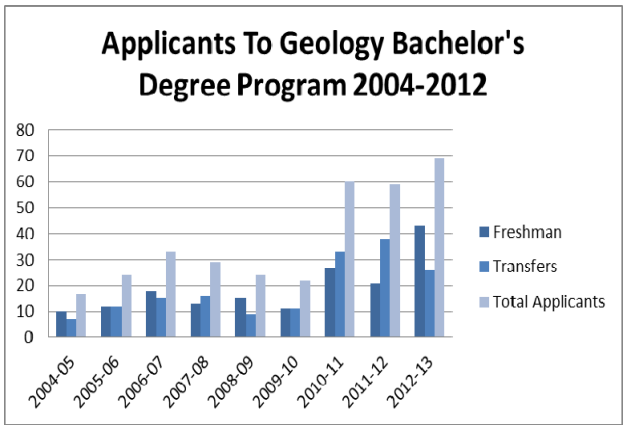
2010-11 Academic Program Review

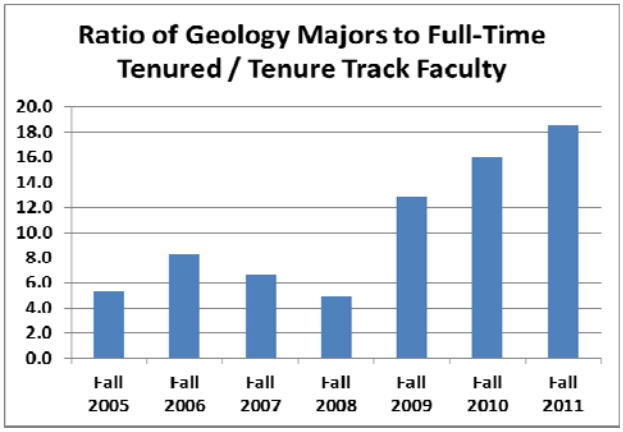
Per CSU requirements, every academic program must be reviewed by external evaluators on a five year cycle. Last year was Geology's turn again, despite the ad hoc review conducted in 2009. We were fortunate to recruit two very knowledgeable evaluators: **Dr. Vicki Pedone**, Professor and Chair of the Geology Department at CSU

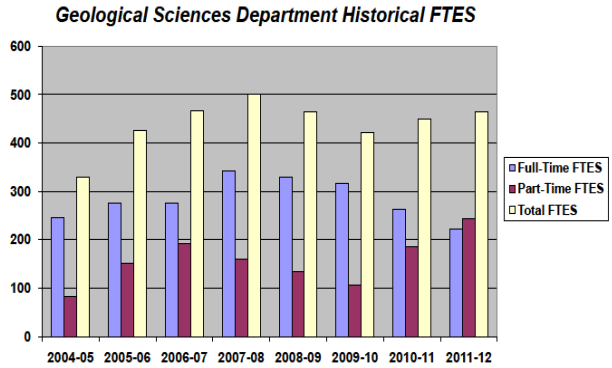
Northridge, and **Mr. Matthew Shumaker**, Chief Mineral Examiner, U. S. Department of Interior Bureau of Land Management. Vicki contributed her experience as faculty member and administrator of a sister CSU Geology Department, while Matt (a 1978 Cal Poly Pomona Geology alumnus) brought his historical perspective on the Department plus more than three decades of work experience in the minerals industry, which is now thriving. The external review was conducted May 13, 2011.

Before the external site visit could be scheduled, a comprehensive Self-Study document needed to be written. This task fell upon the Department Chair—you may view the result at http://geology.csupomona.edu/academics.htm . Below are a few of the charts and graphs from the Self-Study report that underscore the Geology Department's accomplishments, including significant enrollment growth. Some charts are updated with Fall 2011 data. A common theme of the external reviewers' comments was the importance of hiring new faculty members to replace the three veteran members of the Geology Department (Drs. Klasik, Jessey and Berry) who are now teaching half-time under the Faculty Early Retirement Program:









Personal Teaching and Research Notes (Jon Nourse)

This fall I am teaching GIS Applications II (GSC 311/L) to a group of 20 students in the Geography GIS lab. To break up the long laboratory sessions, we spent two days in mid San Antonio Canyon and Bonelli Park acquiring various field observations with coordinates. Students learned to create custom maps of this field data in ArcGIS. All have finished the final exam. Now it is my turn to evaluate it before departing on a mapping trip to Mexico. The "**ArcGIS User's Manual for Geologists**" I have written for this class is still evolving. This year's version contains details on how to create geo databases with multiple feature class layers, and how to digitize and code various lines, polygons, point attributes and annotation. If anyone is interested in reviewing a copy, let me know and I can send it in electronic form.

As the Geology undergraduate program grows, we all have more students to supervise on projects. A senior project is required of all Geology majors. Currently we have about 70 majors if you count the double majors. Two of my students presented their theses last May: Jeff Pepin spoke on "**Geology of Hawk Canyon, Anza-Borrego Desert State Park, California**" and Kelly Kind-

er presented "**Geologic, Structural and Geochemical Relationships in Southern Bonelli Park Near the I-57 Landslide Site**." You may view their theses on our web archive at http://geology.csupomona.edu/thesis.htm. Meanwhile several other students are in various stages of completing their projects. Audra Hanks, pictured later, is working on a correlation of pebbles in the Lower San Antonio Canyon terraces and debris flows with potential bedrock sources on Sunset Ridge and Potato Mountain. Jennifer Kurashige and Christina Bloom completed hydrology -related field studies in San Antonio Canyon last summer, with funding from the summer CCRAA grant program. Jennifer conducted a pilot study of water quality, using our new multi-parameter water quality meter. Christina measured surface flow and determined base flow recession constants in the mid canyon area between Hogback and Sierra Powerhouse. Both are writing their theses over the holidays. Tony Mack chose a mapping project near his desert property in the Twenty Nine Palms area. I eagerly await some results.

I continue to work on three mining prospects in Sonora, Mexico with the support of Colibri Resource Corporation. Over the past year they funded two trips to Mexico as well as trips to mining conferences in Vancouver and San Francisco where I presented the latest results. Colibri Corporation also supports our Geology program through donations to the Field Experiences Fund and annual purchase a Google Earth Pro software license for our student computer lab. The Colibri gold property (located northwest of Caborca, described in previous issues of the Mylonite) was recently joint ventured to Agnico Eagle (a major gold mine development company). Current focus is on a high grade Silver-Zinc –Lead skarn deposit located about an hour drive northeast of Hermosillo. The skarn is encapsulated in a large porphyry intrusion which exhibits alteration patterns and geochemical anomalies suggestive of something bigger—perhaps a porphyry copper deposit? This 4000+ hectare "Ramard" property still needs a fair amount of mapping. Those of you interested in mineral deposits can view more details at http://www.colibriresource.com/

I look forward to teaching Structural Geology (GSC 333/L) this winter, with a large group of 30 students enrolled. This will stretch our new field vehicle capacity to the limit (and then some). Camping out on the two scheduled weekend field trips should be interesting —we will need to bring lots of firewood. Unfortunately I cannot buy food for the group and then divide up the costs, as we did in the past. However, the logistics on these trips will be eased through the assistance of Mike McAtee, whose job description was recently altered to accommodate significant support for Geology Department field trips.

I close my comments with some photos of gold nuggets that keep me inspired about the geology of Sonora. Perhaps this may become our new global currency in the not too distant future?? Best wishes to all of you, and have a healthy and festive holiday season!

Jon Nourse
janourse@csupomona.edu

Nuggets from placers washed out of bedrock sources in the Sonora gold belt. I own the one on the left—it's about 3 cm in diameter

One of the more unusual nuggets from the Sonora gold belt showing gold-permeated fractures in a hydrothermally altered Jurassic andesite host

Graduation, 2011

Nine Geology and Integrated Earth Studies majors walked in last year's graduation ceremony. Pictured below with Drs. Berry, Jessey, Klasik and Polet are (from left to right): Jessy Bruns, Jason Jorgenson, Kevin Kwong, Jeff

Pepin, Kasey Wellington, Kelly Kinder, Celia Pazos and Christina Bloom. Kelly, having the highest GPA of the group, carried the Geology banner. Also graduating, but not present for this picture was Liliana Nunez, who is attending graduate school this year at Scripps Institute of Oceanography.

Part of Geology's June 2010 graduation group after the ceremony. This photo includes Dr. Nourse and Dr. Marshall

Alumni Reunion and 2010-11 Scholarship/Awards Ceremony

This year's alumni reunion was held at Carbon Canyon Park on June 4, 2011. Approximately 45 alumni, friends, faculty and students attended. Thank you all for sharing your various goodies. Below are photos showing the event. Many thanks also to Geology Club members for cooking the burgers and to Phyllis Hosey-Nourse for assisting with food layout and clean-up.

Scholarships and Awards

We are most fortunate that sufficient funds are still available to continue our annual student scholarships:

Henderson-Valles Scholarship

This year's award of $1000 went to **Audra Hanks** in recognition of her academic achievements and future potential as a geoscientist. Audra has been assisting Dr. Nourse on his research along the frontal fault system in the San Gabriel Mountains, comparing pebbles in the San Antonio terraces to bedrock sources on Sunset Ridge and Potato Mountain. She presented posters on this work at the SCCUR and GSA conferences. She is also an officer in the Geology Club. The Geology faculty commends Audra for her accomplishments.

Dr. Nourse presents the Henderson-Valles award to Audra Hanks

Peter K. Valles AGI Glossary of Geology and Rock Hammer Awards

A few years back, **Peter Valles** began providing us a Glossary of Geologic Terms (published by the American Geological Institute) to award a deserving student who might utilize some of these words in future geologic studies. This year we had two glossaries to award. The recipients were **Amber Butcher** and **Kevin Kwong**. Amber is finishing up her studies this year and needs to decide which of her several projects to write about for the senior thesis. Kevin was accepted into seismology programs at two graduate schools: University of Utah and Memphis University. He is attending Utah this year and hopefully making good use of the glossary.

Ernest Prete, Jr Scholarship

To recognize the environmental significance of her senior thesis work on the Cal Poly Pomona campus, **Hannah Potter** received the Prete award of $1000. Hannah is one of Jascha Polet's mentorees. Hannah is graduating in June of 2012. She presented her thesis study one year early last May: "Gravity Profiles across the San Jose Fault on the Cal Poly Pomona Campus: Citrus Lane and Quad Profiles". Hannah was accepted into Stanford University's SURGE internship program last summer. She will finish her degree Spring 2012.

Dr. Polet and Dr. Nourse present the Prete award to Hannah Potter

Margaret Claire Van Buskirk Memorial Scholarship

His $750 scholarship recognizes a student who exudes enthusiasm for geology and dedicates significant time to better the learning environment around the Geology Department. This year's award was given to **Josh Sargent.** Josh has been active in Geology Club and serves as their President this year. He has been very helpful with the logistics of many large field trips, and has been officially cleared to drive the truck when faculty leaders get tired. He spends much time around the department rallying the students, providing encouragement and motivation. The Geology faculty greatly appreciates Josh's contributions to the Department.

Josh Sargent receives the Margaret Van Buskirk award from Dr. Nourse and Dr. Klasik

Brunton Compass Award

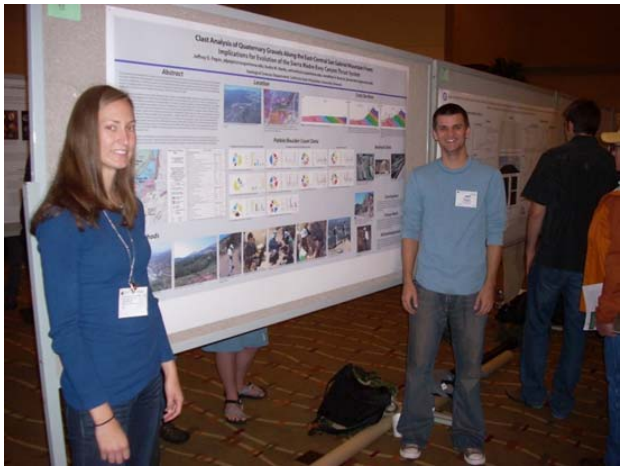
This year the Geology Department had enough surplus funds to award a well-deserved Brunton Compass to Greg Van Oosbree. After careful consideration we chose Greg as the student most likely to make good use of a Brunton. Greg spent the summer in Alaska, working for S.J. Geophysics LTD on an electrical geophysical survey. Greg, we hope you had a chance to break it in

Dr. Nourse presents the Brunton compass to a very surprised Greg Van Oosbree

Student Poster Presentations

More Geology majors equates to more senior projects and related presentations. Many of our students presented their work last year at various professional venues. Below are some pictures. Several students presented at more than one event—I tried to pick the best shot of each participant.

GSA Rocky Mountain /Cordilleran section meeting in Logan Utah, May 2011:



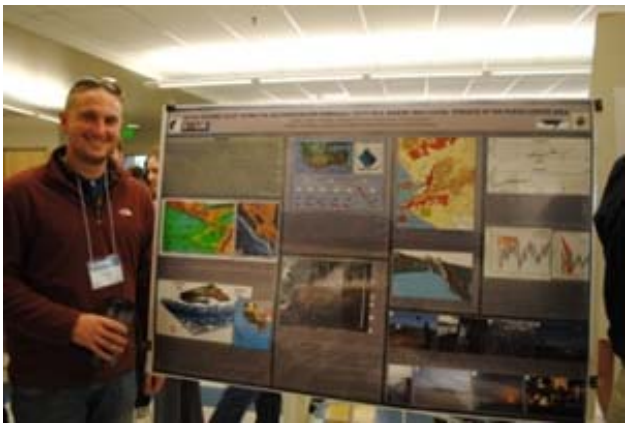
Audra Hanks and Jeff Pepin present their poster on the San Gabriel Mountains frontal fault zone

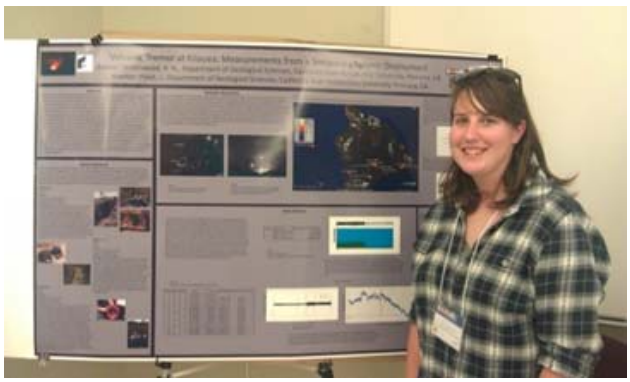
Jessy Bruns was awarded a second place undergraduate poster award for this presentation at the Rocky Mountain/Cordilleran Sectional meeting

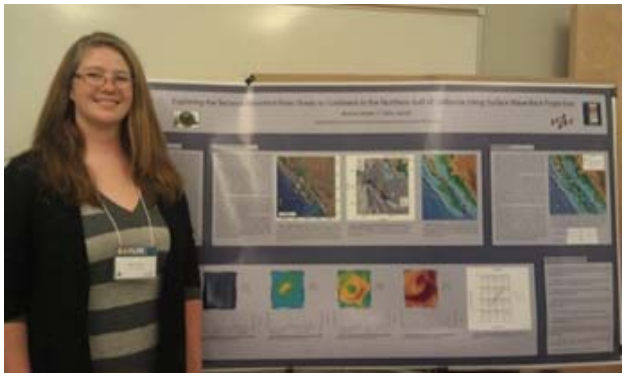
Kevin Kwong's poster describes an algorithm to determine earthquake fault parameters from aftershock locations of the 2011 Japan earthquake

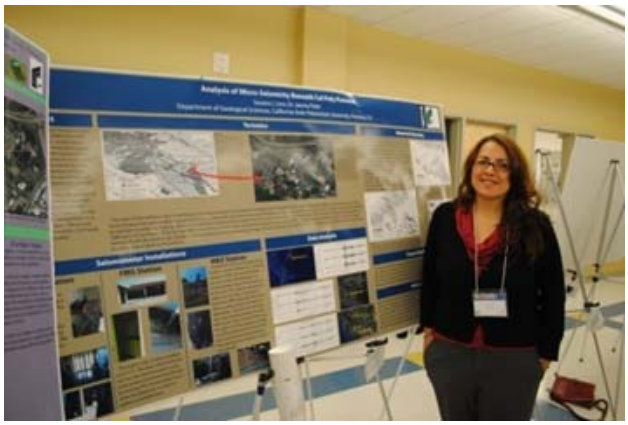
Hannah Potter and Celia Pazos present their gravity study

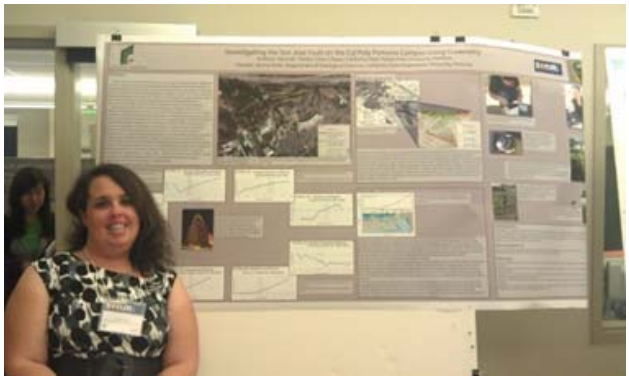
Southern California Council on Undergraduate Research (SCCUR) conference at Mt. San Antonio College, November 2011:





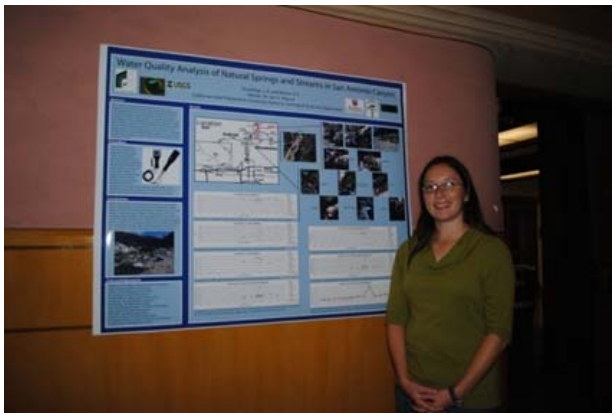






Kennis Ho, Brent Ritzinger, Kacie Wellington, Becca Greenwood, Amber Butcher, Susana Lino and Hannah Potter present their various works. Jennifer Kurashige and Christina Bloom presented talks early that morning

USGS / Community College Networking Symposium at Pasadena City College, November 2011: This venue was fairly dark, but here is a photo of



Jennifer Kurashige that turned out

Other Geology Student Successes

The Geology Department wishes to congratulate our students who will be pursued summer internships or were accepted into graduate school:

Internships and Summer Research (2011)

- Hannah Potter was accepted into the Summer Research in Geoscience and Engineering (SURGE) program at Stanford

- Amber Butcher was selected as a McNair Scholar and will be working on her Costa Rica research project with Dr. Jeff Marshall

- Celia Pazos was accepted into the Summer of Applied Geophysical Experience (SAGE), which is a program designated to introduce students to geophysical exploration and involves extensive hands-on field experience.

- Jennifer Kurashige was awarded a $500 scholarship from Groundwater Resources Association to offset costs associated with her senior thesis project in the San Gabriel Mountains. Jennifer is monitoring water quality of several springs in Upper San Antonio Canyon.

- Christina Bloom, Jennifer Kurashige, Rebecca Greenwood and Susana Lino were funded over the summer by the CCRAA Undergraduate Research Apprenticeship program. "Apprentices" Christina and Jennifer worked with Dr. Nourse on separate hydrology studies in the San Gabriel Mountains. Rebecca and Susana used the new seismometers under Dr. Polet's guidance to monitor earthquake activity near Kilauea volcano and on the Cal Poly Pomona campus.

- Josh Sargent and Brad Lawry returned to Alaska for a second year in a row to work for S. J. Geophysics, LTD. They carried out an extensive Induced Polarization- Resistivity survey of a copper-gold property near controlled by Corvus Gold, Inc. near Mt. McKinley. This year Josh and Brad recruited Geology major Greg Van Oosbree to join the project. Below are pictures from last year's endeavors:

View from camp

Helicopter pickup

- Kacie Wellington worked in Alaska this summer, for Alaska Earth Sciences, Inc., a consulting firm associated with one of Newmont Mining Corporation's many gold properties. Kacie collected soil, rock, and stream deposit samples near McGrath, Alaska, close to the Alaska Range.

Admitted to Graduate School, Fall 2011!!

- Kevin Kwong is attending graduate school in Geophysics at the **University of Utah**, Salt Lake City

- Liliana Nunez has joined the Climate Group at **Scripps Institution of Oceanography** at UC San Diego for her graduate degree.

Faculty News

Dave Berry

The big news this is that I started FERPing in September. So the journey to retirement has begun.

This past year all of my classes were packed including my first FERPing quarter this Fall Quarter. However, in winter quarter I will have only two classes and only one in the Spring (Paleontology). Fortunately, enrollments in basic geology courses have remained high at Cal Poly despite California's economy.

Our drive home from Laramie, visiting Lara, last summer took us to/through Dinosaur National Monument in Utah. My travels in the Golden State continued throughout the year including my continued informal survey of southern California paleontology resources, mostly in San Diego County, where the decline in construction has resulted in a shortage of new salvage projects and consequently fewer new fossil discoveries.

In February I traveled to the Museum of Paleontology at Berkeley (UCMP) for a short course involving global climatic change. The focus was on how climate change, and resulting sea level rise, will affect the San Francisco Bay Area.

In July I hosted a class of young students from the Children's Center for a "show and tell" on dinosaurs and fossils. More recently (November) I gave a tour of the Bernard ("Bernie") Lane Paleontology Laboratory and its resources to Joan Leong's Invertebrate Zoology class. The students were particularly interested in corals and sponges and I was able to show them a variety of fossils of these groups. Also in November I was invited to give a guest lecture on human paleopathology to Dr. Dave Lord's forensic anthropology class.

I was again at UC Berkeley in August to participate in a symposium/workshop on the teaching of evolution. Topics at the conference included cladistics, phylogenetic trees, and "evo-devo" (evolutionary genetics). Some of what was discussed already has been incorporated into my GSC 151L class (Earth, Time, and Life Laboratory).

Also in August I attended an informal meeting of paleontology students at CSU Stanislaus – the site of the most recent Cal Paleo conference. The Geology Club at CSUS is active in a variety of paleo projects, particularly an ongoing study of Cretaceous dinosaurs collected in the Big Bend region of West Texas. The project is directed by Dr. Julia Sankey who is professor of geology and paleontology at CSUS. A field trip to Big Bend is being planned for

January and interested students from other CSU campuses are invited to attend.

Marianne Grillo continues working in the Bernie Lane Paleontology Laboratory as assistant curator and paleontology technician. She is responsible for maintaining the collections and the lab. Marianne continues to work on the development of an electronic data retrieval system, which will allow us to know the location and history of **any** fossil specimen in the collections of the Bernard O. Lane Laboratory of Paleontology.

I wish you all an enjoyable holiday season and the very best in 2012.

David Jessey

This year marks the third year of my FERP (Faculty Early Retirement Plan). It was supposed to ease me into retirement by reducing my teaching load. It has done that, but other things seem to fill the void so I am no less busy than I was. I decided to deal with that by announcing my plan, last spring, to fully retire at the end of the 2011-2012 academic year. I have been asked to reconsider for at least another year, so I may be around yet again next year.

My consulting business is booming. I currently am managing a regional rare earth/precious metals exploration project for an Australian client that employs several students and associates. We are looking at several prospects in California, Nevada and Arizona. That project takes up most of my non-teaching time. However, I have also consulted for a Canadian firm developing a rare earth deposit in southern Nevada and a silver company working in the Calico Mountains near Barstow. I have been successful in finding senior thesis and Master's funding for several students who are looking at various precious metal and rare earth properties. The companies say they can't find qualified geologists to fill their staff positions so they are relying on me to provide student interns and junior geologists. Jobs are so plentiful it's hard to keep the students focused on completing their degrees. The bottom line for me has been that I have so much consulting work that I am finding it necessary to refuse business or recommend others!

I coauthored a GSA abstract with Jessy Bruns on rare earth mineralization in southern Nevada. Her poster won an award for best student paper at the GSA Cordilleran/Rock Mountain meeting in Logan, Utah this past spring. She has completed and posted her thesis on the rare earth mineralization at http://geology.csupomona.edu/theses/JJBruns.pdf. It makes excellent reading if you have the time.

Last year we did field trips to northern Nevada for Mining and Exploration and the Mother Lode for Ig-Met.
I made arrangements with Barrick Gold, near Elko, Nevada for an underground mine tour for M&E. Few students ever get the opportunity to visit a working underground mine. I wasn't all that impressed with the place, looked like a big underground parking garage, but the students sure enjoyed it. We even managed to get a little snow on Day 2 on the way to visit Randal Burns in Ely, Nevada.

In the spring we went to the Mother Lode and Yosemite with Ig-Met. I didn't do the normal Owens Valley trip as much of the Mammoth area was still snowed in. Instead, I opted to go up the west side of the Sierras. Figured that way we would avoid the snow. I was wrong! On the first night in rained and snowed like crazy. When we tried to get into Yosemite in the morning the road was closed. We sat around and decided what to do thinking we would just turn around and go home. Just as we were leaving the CalTrans sign said the road had reopened. We drove up into the valley and were greeted with the most magnificent views I have ever seen. The snow was fresh and covered everything; spectacular pictures. I posted a brief blog with pictures online at http://geology.csupomona.edu/yosemite.pdf.

I went to the Tucson Germ and Mineral Show last year. However, as I am running out of room in my house to display my mineral collection I had to be judicious with my purchases. I hope to go again this year, but my consulting schedule may present a problem. I really enjoy the show; just have to realize there is a limit as to how many mineral specimens I can own before I have to buy a separate building to house my collection. This Fall I opted out of a Mineralogy field trip. I'm not teaching anything with field trips in the winter, but in the Spring I will be headed over to Arizona with Ore Deposits. Hope to get underground at the Gold Road near Oatman and into one of the porphyry copper mines near Tucson.
.
On the home front, my son graduated from Cal Poly in the spring with a degree in aeronautical engineering. He has done nothing in terms of looking for a job. Better to freeload off his parents. My daughter is also out of work, but jobs are hard to find for someone with a Drama degree. Rose continues to work for the Chino School District, Sakari get her twice daily walks and Boris and Natasha do whatever it is that cats do. Best Wishes to everyone for the coming year. Hope all of our alums keep in touch and that Julie Brown finds a warn spot in Antarctica! Oh and congratulations to Julie and Daniel on their recent wedding.

John A. Klasik

Greetings to all you fine alumni. I have had a good, quiet,

rather uneventful year. I sincerely hope your 2011 has been good to you.

As you know, our alumni reunion was held rather late this year, in early June of 2011. Hopefully we can move it back away from the end Cal Poly's academic year and away from the conclusion of many of your school years. I'd like to see it back toward the end of April or early May (just not the weekend including May 20, 2012, see below). I truly appreciated seeing all those who were able to attend this year's event. I am glad you managed to fit us into your rather full schedules. It is always great to come to a reunion and celebrate your association with the Department, your accomplishments and those of the Department. I enjoyed talking to our "regular attendees" – Charlene, Terry, Randal and Arleen, for example. I was also glad to see some "new comers and old returnees". I hope Azad Khalighi (**'08**) is enjoying Law School and will mark his "docket" for future alumni reunions. I must admit, without his name badge I did not recognize Leo Mercy (**'78**). Leo has been a loyal alumnus, but I had not seen him in a few years. My little gray cells just could not quickly make the connection. Nevertheless, I had a great conversation with Leo and his wife. We hope Leo can make our reunion a regular event.

Matt Willis (**'09**) completed and defended his Master's thesis in June of 2011. As you know from last year's *Mylonite* I was one of Matt's thesis committee members. My experience working with Matt was nothing but positive. He gave a great oral presentation and successful defense of his study. His study and presentation were very well received by faculty and students.

I continue to work with Materials Science engineering students conducting X-ray diffraction studies of their "concoctions". All of the students continue to be a pleasure to work with. Their materials continue to be fascinating and a challenge. This year's studies included, ferro liquids as well as creams and gels. It was fascinating to see a ferro liquid immediately acquire structure when placed near a magnet.

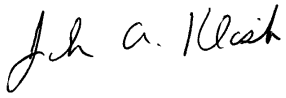
I welcome Dr. Steven Osborne to our faculty ranks. Dr. Osborne's expertise in hydrogeology will add an entirely new dimension to our faculty and curriculum.

I am now entering my third year of FERP'ing, aka partial retirement. Once again I am teaching half time. Thus far, I have enjoyed the reduced assignment and have been pleased to have more free time. As this academic year comes to a close in 2012, I will once again re-assess whether to continue in my current half time capacity or not.

This year we took two trips to the east coast. We traveled there over Christmas 2010. We had reservations to fly back to California on December 27th. Then the huge 20 plus inch snowfall of December 26 happened. Our flight, as was hundreds if not thousands of others, was cancelled well in advance of its scheduled departure. We had the pleasure of being on hold for almost two hours before we could talk to a ticketing agent only to find out we could not be re-booked until five days later. We eventually flew back to Ontario on a different airline, but still had to wait three additional days. Our second trip east was in July to spend our traditional week on the south Jersey shore (well before Hurricane Irene did her thing). As always it was good to be part of the family reunion. The Atlantic water temperature was cool but I could eventually get wet and enjoy the waves.

The year 2012 is a big year in astronomy so mark your calendars: May 20, annular eclipse of the sun (Reno, for example), June 5, the transit of Venus (West Coast), the last transit until 2117, November 14, total solar eclipse (N. Australia and the South Pacific). Hopefully, these three major events in one year will not trigger the Mayan Calendar's end of the world.

That does it for this 2011 edition. I hope to see many of you at the 2012 alumni reunion. I hope all of you are well and enjoying your life. Have a great 2012
Best regards,



Jeff Marshall

Greetings distinguished alumni and other assorted geo-people!

Another fine year has zipped past at light speed. On the research frontier, my Costa Rica project continues chugging forward at full steam. Last year, I wrote to you from the AGU conference in San Francisco where my student research team presented a poster on the results of our first NSF funded field season in spring 2010. This year, we returned to Costa Rica again at spring break for more fieldwork on the Nicoya Peninsula funded by NSF and a new grant from the Kellogg Foundation. Our field team included last year's group, Shawn Morrish ('10), Amber Butcher, Brent Ritzinger, and Kacie Wellington, plus two new team members, Andrew Barnhart and Kelly Kinder. To learn more about our 2011 field excursion, please read the NSF "field blog" attached at the end of this Mylonite issue.

I taught my usual array of courses again this year, including another round of the new Watershed Restoration course

through the Lyle Center for Regenerative Studies. This year, geology majors dominated the class showing off their field skills in developing some very cool restoration plans for local streams. I also had a great time leading another fine field module studying the classic marine terraces and coastal tectonics of the Santa Cruz area. In addition to excellent geology, we enjoyed several memorable evenings around the fire ring at our campsite on Sunset State Beach.

Aside from research and teaching, I continue to work with the campus research office as University Coordinator for Undergraduate Research. As part of this effort, I led a faculty team in writing a successful grant proposal to the Kellogg Legacy Fund for a student scholarship and mini-grant program referred to as "Kellogg FuTURE". I also worked with the CSU Chancellor's office to craft a successful system-wide proposal for the creation of a CSU Undergraduate Research Consortium. On a national level, I continue to serve as a Geosciences Councilor with the Council on Undergraduate Research (CUR), and as a member of the Education Advisory Committee of the new NSF GeoPRISMS Program. Twice this year, I served as conference convener and grad-student program coordinator for GeoPRISMS planning workshops, first in January, for the Subduction Cycles and Deformation workshop in Bastrop, Texas, and then in September, for the Alaska Primary Site workshop in Portland, Oregon. The Portland workshop included a great field trip exploring the volcanic stratigraphy of the Portland basin and Columbia River Gorge.

Other fun travel this year included family vacations to Santa Cruz and Ohio. Our Santa Cruz adventure featured walks along the cliffs to see sea otters and monarch butterflies, as well as a vintage train ride through the redwoods. In mid-summer, I traveled back east with Kyle to explore his Ohio family roots. My mom joined us to walk the streets of her old hometown, visit our cousins among the cornfields, and seek out ancestors in country graveyards. Kyle thrilled at his first encounters with fireflies, hogs, and summer thundershowers. We then drove up to Toledo for a family reunion of the Marshall clan. Highlights included a walk on Lake Erie, a Toledo Mudhens game with fireworks, and Kyle learning the art of archery from his bow hunting cousin Bill.

Kyle gets bigger and brighter every day, and still tells me he wants to be a geologist when he grows up. He loves learning and playing sports. He continues to play soccer, and this year started Little League baseball. He had a great time this summer at the Cal Poly Pomona baseball camp, and still proudly wears his green and gold Broncos hat. Okay, until next year, that's all folks!

Stephen Osborn

I am very happy to join the Geology Department at Cal Poly Pomona. The students and faculty have been fantastic during my first quarter here. Since this is my first Mylonite, I thought that I would introduce my background and research interests in addition to describing my activities since arriving in the department. I grew up in Riverside and completed my B.S. and first M.S. degrees at UC Riverside in environmental science and soil science, respectively. Following my time at UCR, I took a position with the USDA as a physical science technician at the Columbia Plateau Conservation Research Center in Eastern Oregon and then worked in the consulting industry for 6 years. Working as a consultant provided a great opportunity to travel all over the US conducting field studies, installing a variety of groundwater wells, and completing remedial feasibility tests. I developed my interest in water quality and hydrogeology during these years. As a result, I decided to go back to school for a second MS degree in Geology at Georgia State University (completed in 2006). I then went to the Hydrology and Water Resources Department at the University of Arizona (UA), where I completed my Ph.D. with a minor concentration from the Geosciences Department. My dissertation work focused on the geochemistry and paleo-hydrogeology of basinal fluids in the northern Appalachian Basin associated with the Alleghanian Orogeny and the effect on recent microbial processes in the subsurface. Using water-rock reactions as tracers of fluid flow and other physical processes such as diagenesis is a major research interest that I plan to foster throughout my career. Subsurface microbial processes are a second research interest, resultant from my dissertation work, which could have implications for remediation of contaminated groundwater as well as understanding microbial methane as a resource in areas with abundant organic-rich shales or subsurface organic matter.

I had very little time to celebrate the completion of my dissertation. The day after I turned in my final dissertation (June 2010) with all of the edits completed and approved to the UA, I packed-up my apartment in a frenzy and hit the road to North Carolina. Three days later, I started as a post-doctoral researcher at the Center on Global Change in the Nicholas School of the Environment at Duke University. I worked on projects there that investigated the potential environmental impacts to groundwater resources and water quality associated with 1) carbon geo-sequestration, and 2) natural gas extraction and hydraulic fracturing. The second project was recently published in the Proceedings of the National Academy of Sciences and has developed into a third major research interest squarely at the nexus between environmental and energy issues. I believe that this research direction could have important implications for sustainable and clean energy production,

while also protecting water resources.

This first quarter at Cal Poly has been a busy transition with teaching and establishing the water quality laboratory. I taught the Physical Geology Laboratory, which has been great. It has allowed my to interact with many of the geology majors in the department, and introduce geology to non-majors. I've also been working on developing my lectures and lesson plans for the Hydrogeology and Geochemistry classes that I will teach in the Winter Quarter (2012). I am really looking forward to working with students on these subjects that are directly within my expertise and what I am most excited about. Currently, I am preparing a proposal for a new lower division class that will introduce basic hydrologic science and water resources issues to undergraduate students. I hope this class, if accepted by Cal Poly, will not only be a gateway for water interested students to become geology majors, but also a good class for non-majors to fulfill science requirements and increase awareness of critical water related issues in California, the southwest, and across the US.

This quarter has also been busy with establishing the water quality laboratory. This summer (after my hire paperwork was finished), I purchased a Dionex Ion Chromatorgaph. This instrument will be used to analyze major, minor, and some trace anions in water such as sulfate, chloride, and nitrate among others in the parts per billion range. This instrument can also be upgraded for analyses of select compounds in the future as the water quality laboratory grows. The other major purchase from my start up package is a Milli-Q water ultra-purification system, which will be necessary for analyses of samples and trace elements in the parts per billion range. These instruments compliment the atomic adsorption spectrometer (used for analyses of select cations), already in the department, and combined are necessary for assessing basic water quality. I am working on a grant proposal that will expand the research capabilities of the water quality lab by acquiring a water (oxygen and hydrogen) isotope analyzer, which will be submitted this January. This proposal will be submitted to the National Science Foundation (NSF), Major Research Instrumentation Program in January and is a collaborative effort with researchers in the Biology Department. The water isotope analyzer will be used for investigating the source and migration pathways of fluids in the environment and other ecosystem functions. Acquisition of this instrument should also attract important collaborations from across campus (e.g., Biology and Agriculture), and within the California State University System, Water Resources and Policy Initiatives Program, of which I have become a recent research faculty member.

I was asked this past November to give a keynote talk entitled, "Natural Gas Extraction and Hydraulic Fracturing, an Environmental Perspective" at a conference sponsored by the INSTAAR Institute at the University of Colorado. I was able to establish a collaboration with researchers there that will lead to an NSF proposal submission this spring that investigates more closely the potential for air, water, and societal impacts from hydrocarbon extraction. I hope that this will be a successful grant submission that will involve students. In addition, I am working on grant proposals that will extend some of my work in areas of natural gas extraction in Pennsylvania and New York. I am also developing ideas for research in the Central Valley of California, the Sierras, and the Los Angeles Basin and Inland Empire that I hope will take off in the coming year. I look forward to discussing the progress of these projects in next year's Mylonite. Happy Holidays.

Jascha Polet

I'm writing this Mylonite article in San Francisco, attending the American Geophysical Meeting. Tomorrow I will present my poster on the Hawaii seismic experiment, a 6-day deployment on the Big Island of Hawaii that I carried out with the help of eight undergraduate students (pictures of this field experiment can be found at http://geology.csupomona.edu/jpolet/Jascha_Polet_at_Cal_Poly_Pomona/Hawaii_Field_Experiment_Photos.html

Thanks to funding from the Cal Poly Pomona ADVANCE grant and the Geological Sciences Department, we were able to acquire three broadband seismometers last year and we immediately put these instruments to good use in Hawaii. We recorded several episodes of volcanic tremor and numerous earthquakes, and Rebecca Greenwood is currently analyzing this data for her senior thesis project. Upon return from Hawaii, the seismometers were installed in several locations on campus; Susana Lino and Kennis Ho are now using these waveforms for micro-zonation and micro-seismicity studies for their theses.

As you may have gathered from my previous Mylonite articles, when an opportunity to travel presents itself I will not let it pass by. This year, I attended a very educational workshop in Costa Rica on Geophysical Hazards and Plate Boundary Processes in Central America, Mexico and the Caribbean, and I presented my research at the 2011 International Union of Geodesy and Geophysics General Assembly "Earth on the Edge: Science for a Sustainable Planet ", in Melbourne. I also travelled to Etna in Sicily, where I experienced my first "serious" real-life volcanic eruption.
I received good news earlier this year: I received early promotion to Associate Professor and several of my proposals were funded, including projects with the US Geological

Survey and my first grant from the Southern California Earthquake Center. Most of these grants include significant student funding, and Amber Butcher is currently locating earthquakes in the ocean-continent transition zone of the Gulf of California as part of the SCEC grant. I am also spending some time at my alma mater, Caltech, this year, as part of a subcontract on the use of satellite data to determine rapid earthquake source parameters.

Another exciting development is the collaboration between PCC and Cal Poly Pomona on a 5-year project to improve transfer opportunities for environmental science students from PCC to Cal Poly Pomona, both in Geology as well as Environmental Biology. I am looking forward to my role as PI on this grant and have already started work on some very promising initiatives involving shared field experiences and colloquia. Other important aspects of this grant will be student stipends and the acquisition of field equipment.

Students on Mauna Kea

Students in Thurston lava tube

Driving towards an erupting Etna

Staff News

Hot off the presses: We are pleased to report that Mike McAtee was selected for the College of Science Outstanding Staff Award, this December 9, 2011. Mike also received his 30-year service pin from Cal Poly Pomona in September. Mike continues to serve the diverse needs of the Geology Department in addition to managing the wood and metal shop supporting College of Science faculty with odd requests like "Can you fix this?" (for free); or, "Can you build me something that will do….?" Lately Mike has been driving the Geology Department truck on field trips, and assisting with related logistics.

Alumni News, Notes and Photos/ Web Links

I have attempted to piece together the following alumni notes from fragments of emails, phone calls and other communications. Please forgive the messenger if anything got convoluted. Jon Nourse

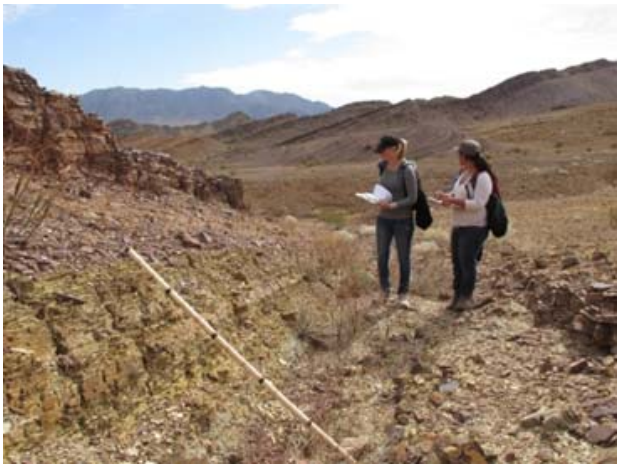
Matt Shumaker ('78) was able to take time away from his job as Chief Mineral Examiner for the Bureau of land Management to provide a comprehensive review of the Geology Program last May. Matt continues to send us job opportunities for recent graduates—several positions have opened recently in Alaska and Montana, among other places. Below is a photo of Matt in the field (on the left); also a shot of his latest field vehicle.

Brian Oliver ('10) writes us from Bakersfield:

Greetings all,
I thought I would update you all on my life since graduation. I miss you all at Cal Poly Pomona and see that some changes have taken place. Congratulations on the Masters Program, I was hoping to return there for my graduate degree, but as some of you may know, I took an internship in Bakersfield at an oil company named Plains Exploration and Production last year. My project was to characterize an unconventional reservoir in the L.A. Basin. Without sharing too many details, an exploration well has been drilled and looks promising. After completing the internship, I was offered continued employment as a contract employee where I worked on the Inglewood oil field. In February, I was offered permanent employment with the company and after almost a year away from home I moved the entire family here. We are all doing well now that we are together. Now that permanent employment has been gained and my family and I are together, I have decided to obtain a Masters Degree in Geology from Cal State Bakersfield.

It was nice to catch up with **Shelby Valanzuela (Marusich) ('99)** and **Allison Ruotolo ('08)** a few days ago. Both are working as geologists for MWH Americas, Inc. in Arcadia. We had a nice visit the day after the windstorm that knocked out power in the San Gabriel valley. One of those rare days when the office could not function! Shelby and Allison also passed on a hello from **Kim Zelmer (Poste) ('09)** who is settling in nicely to a position in the same company

Rob Ellis ('08) is also employed at MWH Americas. We thank Rob helping us out last fall as instructor for the GSC 255L Field Methods course. There were 28 students enrolled! The logistics were eased somewhat by Mike McAtee, who now provides support for Geology Field trips. Below are photos (courtesy of Raymond Ng) from Rob's recent Marble Mountains field trip. Our students still use Brunton compasses and measure sections.



Jason Smith (2011 BSc, Integrated Earth Studies) works for Delta Environmental Consultants, Inc. in Los Angeles. He is Staff Geologist for Petroleum Division, North American Operations. Jason and **Melissa Bonner (2010 BSc Geology)**, who met in class at Cal Poly Pomona, were married last May.

I ran across **Steve Zuker ('81)** a couple weeks ago at the Hard Assets conference in San Francisco. Steve is a member of the mineral exploration team at Esperanza Resources Corporation. The company is going strong with a newly acquired Silver-Copper property in Slovakia and active interests in Mexico and Peru.

Scott McKeag ('82) visited us in November to present a talk about his mining activities in Alaska. Scott provided abundant encouragement and sage advice to our Geology majors about how to succeed in the mineral exploration workplace. We had a nice lunch at Kellogg West. Thanks very much, Scott, for putting together the slide show.

Matt Willis ('09)
Matt Wills says hello from South Carolina and Northern California. Matt has always had a deep interest in studying and protecting earth's environment. In June of 2009, Matt graduated from the Geological Sciences Department with as an Integrated Earth Studies degree. Matt received his Master's of Science Degree in June of 2011 from Cal Poly's Regenerative Studies Center.

As an undergraduate Matt interned for NASA at Moffett Field (Ames Research Center) where, using remote sensing, he analyzed carbon flux from wild fires. In addition he worked for NOAA developing a plan for recovery of the Steelhead Salmon, and evaluated electromagnetic fields from wave energy converters.

In September of 2011, Matt became an "honorary member" (his term) of the North Strand Coastal Wind Team in Myrtle Beach, South Carolina. http://northstrandcoastalwindteam.org/2011/09/matthew-willis-joins-nscwt/

The team is responsible for the planning and installation of wind turbines throughout the city. This is right up Matt's alley. Matt's Master's thesis dealt with evaluating the feasibility of wind turbine derived energy in the San Diego urban environment.

In late November Matt started his "real job" with the county of Mendocino. Matt is the Sustainability and Economic Development Specialist for the county of Mendocino (an old stomping grounds for Matt). We wish him success in the cloudy, rainy, tranquil north country. This environmental position is not the culmination of Matt environmental aspirations. He is currently applying to PhD programs that focus on urban environmental issues / planning. We wish Matt success in his current position and much encouragement in his pursuit of his PhD.

Stephen Mulqueen, ('78), Ventura, CA
After retiring in 2009, Steve continues to remain active with projects related to geology and public outreach. **Steve is currently the Vice President of the California Oil Museum Foundation, Incorporated, a non-profit organization formed on September 14, 2011. The Foundation's main functions are to manage operations and to ensure long-term funding of the California Oil Museum in Santa Paula.** He has been a docent at the museum since the 1990s and presently manages a rock/mineral/fossil exhibit at the museum. The current exhibit features "ventifacts".

Steve is active in the Southern California Section of the Society of Mining Engineers. In January of this year, he

conducted a field trip related to mining history for the SME to the East Mojave and Southern Death Valley regions. During May, Steve presented a lecture at the SME dinner meeting on a subject related to Petroleum Seeps and the early development of the oil industry in California.

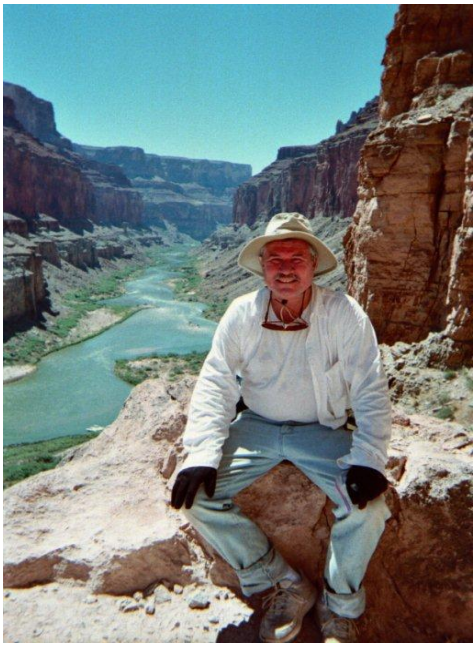
A recent project involved work associated with the Tri-Club Educational Committee, an organization composed of three local gem & mineral clubs of Ventura County. The committee collects specimens and assembles educational rock boxes that are distributed to schools throughout the Ventura Unified School District. The three wooden boxes contain a total of 36 rocks representative of the three rock types. Approximately 125 box sets (out the of the approximately 200+ schools) have been distributed in the District. Funding for these boxes are provided by the Ventura Chapter of the American Petroleum Institute.

Steve and his wife Susan are active as judges and exhibitors at science fairs in Ventura and Santa Barbara Counties. One of the more recent science fairs was held at Mountain View Elementary School in Goleta in October.

Steve continues to work part time with the California State Lands Commission on field projects regarding the assessment and remediation of Abandoned Mine Lands (AML). During the year, he was involved with three field inventory projects located in remote regions of the Mojave Desert.

Steve's great geology adventure for the year involved a motorized raft trip through the Grand Canyon with Tour West during a week in June. The raft trip should be required for all geologists and geology students.

(Written by Susan Mulqueen, Dec. 5, 2011)



THOMPSON FAMILY 2011 CHRISTMAS LETTER

In October of last year, we were given permission to start our house extension. Our plans were to add an extra ground floor room attaching to both the kitchen and the lounge. In addition, we wanted to update our kitchen and move some existing interior walls. Our house now feels like a building site and we are constantly moving our possessions around. We currently only have one working electrical outlet in the kitchen and no lights. We need to walk in a big circle to get from the kitchen to the living room, due to bricked up doorways. Also, some of the rooms look like something out of a horror movie. Early on, we had complications with a vault underlying the proposed extension. Lately, we have been looking at a variety of building materials for the kitchen, bathrooms and bedrooms. The building work will finish before mid-December and the remainder will be done prior to our travelling to Los Angeles next April.

Last December, we had some heavy snow in Taunton. The UK had its coldest December in 100 years! We visited my mother in the warmer Los Angeles area just prior to the 2011 Academy Awards. We were lucky enough to walk down the red carpet the day before the show. It was a good year for the English because "The Kings Speech" dominated the Oscars and it poured with rain! The Los Angeles trips were highlighted by encounters with Wolfgang Puck (chef) and Ashley Tinsdale (A.K.A. 'Candace' from Phineas and Ferb.)

After our trip to the US, Felice went to her ancestral village situated in the mountains between Naples and Rome. Gianpaolo and I made a cake to celebrate her return to Taunton. We went to visit our friends in Kent and saw their impressive 1930's house. During our stay, we visited Broadstairs and saw Dickens' Bleak House. During the summer, Gianpaolo celebrated his First Holy Communion with a family gathering at a nearby hotel. For Gianpaolo's birthday, we went to LEGOLAND. LEGOLAND overlooks Windsor Castle and the trees were then getting their autumn colours. Gianpaolo's favourite rides were the Dragon and Pirate Falls Dynamite Drench...ours was the coffee shop.

I have been involved with a new initiative called Customer Ready Foods and continue to help in the liquor department at our local Marks and Spencer store. Felice has been very busy volunteering at school, taking our son to various extracurricular classes, and selling tickets for the local pantomime. Gianpaolo is studying the Romans at school and likes maths and literacy. His school recently visited Salisbury and Stonehenge! He enjoys watching Dr Who, playing his Wii and building Lego kits. There have been two royal weddings this year. The wedding of Prince William and Kate Middleton in April was a national holiday.

As you may know, November 5th was Guy Fawke's Day or Bonfire Night. The local rugby club, which is adjacent to the motorway, were having a fireworks display the evening before Bonfire Night. Foggy conditions and smoke from the fireworks resulted in a massive accident involving 34 vehicles. This tragically resulted in 51 injuries and 7 fatalities.

With the house in disarray, Christmas will not be up to much this year. We are, however, able to look forward to a good year in 2012 with our remodeling complete, just in time for our trip back to see my mother in April and then the Olympics in London in the summer of 2012. We all hope you have a very nice holiday season and we wish you all our best for 2012!

Gary (**Gary Thompson '90**)

Request for Newsletter Contributions

Please keep us updated about your latest activities or adventures! Photographs and brief descriptions are most welcome. Feel free to include URL links to any web sites, blogs, or photo galleries you would like to share with Geology alumni and friends. We'll try to incorporate the new information into our next newsletter.

A Request for External Support

We in the Geology Department wish to express our sincere gratitude to the many alumni and friends who have made generous contributions in recent times. These gifts have been directed toward fundamental needs that include thin section preparation, laboratory analysis of rock samples, student or faculty travel to GSA and other professional conferences, field vehicle expenses, campground and parking fees, and purchase of field or laboratory equipment, camping gear and firewood. Several gifts have supported our annual scholarship funds.

These are challenging economic times for everyone. That is why your gift at this time will be especially meaningful to all of the students and faculty in Geology. In making your gift, we ask that you mail your check payable to **Cal Poly Pomona Foundation** to the address below. If you wish your contribution to be directed to a particular emphasis, please indicate so on your check:

Geology Department
3801 W. Temple Avenue
California State Polytechnic University
Pomona, CA 91768

Thank you so much, and we really appreciate your continued patronage.

Faculty and Student Scholarly Activities (2010-11)

The accomplishments below are from our annual report compiled by the Department Chair each July. This time we were asked to report activities only from the 2010 Calendar year.

1. Research, Scholarship and Creative Activity

a. Externally peer reviewed, critiqued, juried, and/or judged

David Jessey:

Jessey, D.R., 2010, Geology and Ore Genesis of the Calico Mining District, in Reynolds, R.E., ed., Overboard in the Mojave: 20 million years of lakes and wetlands, California Desert Studies Symposium-2010, Zzyzx, CA. p. 213-223.

Jeffrey Marshall:

Montero, W., **Marshall, J.,** Kruse, S., and Lewis, J., 2010 (submitted December 2010), Neotectonic faulting and fore arc sliver motion along the Atirro-Río Sucio fault system, Costa Rica, Central America: Geological Society of America Bulletin.

Marshall, J., Morrish, S., Butcher, A., Ritzinger, B., Wellington, K., LaFromboise, E., Protti, M., Gardner, T., and Spotila, J., 2010, Morphotectonic segmentation along the Nicoya Peninsula seismic gap, Costa Rica: Eos, Transactions, American Geophysical Union, v. 91, Fall Meeting Supplement, Abs. T11D-2138.

Spotila, J.A., Kennedy, L.M., Durden, A., Depew, K., Smithka, I., Cunningham, C., **Marshall, J.S.**, Prince, P.S., and Tranel, L.M., 2010, Paleoseismic investigations of the Middle America Trench on the Nicoya Peninsula, Costa Rica: A feasibility study of the Tamarindo estuary: Geological Society of America, Abstracts with Programs, v. 42, no. 5, Abstract 250-3, p. 594.

LaFromboise, E., **Marshall, J.**, Simila, G., Protti, M., and Quintero, R., 2010, Neotectonics of the Nicoya Peninsula, Costa Rica: Geological Society of America, Abstracts with Programs, v. 42, no. 4, p. 100, Abstract 48-12.

Morrish, S.C., Butcher, A.J., Ritzinger, B.T., Wellington, K.L., and **Marshall, J.S.**, 2010, Tectonic geomorphology and earthquake hazards of the Nicoya Peninsula seismic gap, Costa Rica, Central America: Geological Society of America, Abstracts with Programs, v. 42, no. 4, p. 64, Abstract 18-25.

Jonathan Nourse:

Nourse, J.A., Carey, L., Bautz, M.L., and Reilly, J.P., 2010, *Hydrogeology of Icehouse Canyon Contrasted withUppper san Antonio Watershed, san Gabriel Mountains, California,* in Clifton H. E. and Ingersoll, R.V. (eds.) , Geological Excursions in California and Nevada: Tectonics, Stratigraphy and Hydrogeology, Field Trip Guidebook for Geological Society of America Cordilleran Section Meeting, Anaheim, California., May 27-29, pp. 323-348.

Anderson, T.H., and **Nourse, J.A.**, 2010, *Contrasting Proterozoic Basement Complexes Near The Truncated Margin Of Laurentia, Northwestern Sonora-Arizona Border Region: Implications For Rodinia Reconstruction*, Geological Society of America Abstracts with Programs Vol. 42, No. 5.

Nourse, J.A., 2010, *Investigation of the February 18, 2010 Landslide Along the Interstate 10- 57 Freeway Connector*: Abstract in Stories of Teaching Success, California State Polytechnic University, April 28.

Nourse, J.A., and Irwin, J.J., 2010, *Tectonic and structural setting of gold mineralization in the Sonora-Mojave belt: example from the Juarez-Tajitos area*, Geological Society of America *Abstracts with Programs*, Vol. 42, No. 4, p. 108.

Bautz, M. and **Nourse, J.**, 2010, Synopsis of Icehouse Canyon Hydrogeology from Observations of the Mid 1990's, in Saint, P., Herzberg, M. and Zaprianoff, B., (eds.), Geology and Hydrology in the Eastern San Gabriel Mountains Through the River of Time, Field Trip Guidebook for South Coast Geological Society, June 18-19, pp. 281-288.

Heaton, D., and **Nourse, J.**, 2010, Comparison of Late Cretaceous Plutonic Rocks across the left-Lateralsan Antonio Canyon fault, San Gabriel Mountains, California, in Saint, P., Herzberg, M. and Zaprianoff, B., (eds.), Geology and Hydrology in the Eastern San Gabriel Mountains Through the River of Time, Field Trip Guidebook for South Coast Geological Society, June 18-19, pp. 117-124.

Jascha Polet:

Thio, H.K., Somerville, P.G. and **Polet, J.**, 2010. Probabilistic Tsunami Hazard in California, Pacific Earthquake Engineering Research Center Report 2010/108, 331pp.

b. NOT externally per reviewed, critiqued, juried, or judged

David Berry:

Conference on mechanics of evolution ("Evo-Devo – How evolution works"), Department of Integrative Biology, University of California, Museum of Paleontology, Berkeley, CA, August 2010 (Participant)

Cal Paleo Conference, California State University, Stanislaus, Turlock, CA, January 2011 (Participant)

Continued work with the Friends of the Natural History Museum, San Diego in fossil salvage and preservation.

Jeffrey Marshall:

Marshall, J.S., 2010, NSF MARGINS Field Expedition Data: Nicoya Peninsula, Costa Rica, Central America: Marine Geoscience Data System, Expedition Meta Data Portal, Lamont Doherty Earth Observatory, Columbia University [Web Site]: http://www.marine-geo.org/tools/search/entry.php?id=CentralAmerica:Marshall

Jascha Polet:

The Math You Need, When You Need It 2010: A workshop for faculty teaching introductory geoscience, implementation plan: http://serc.carleton.edu/mathyouneed/implementations/47516.html
Using on-line volcano monitoring data in college and university courses: The Volcano Exploration Project: Pu`u `O`o (VEPP), 2010, lesson plan: http://nagt.org/nagt/vepp/examples/47268.html

2. Scholarship with Students

a. Research involving students as researchers

David Berry:

Lilibeth Wenceslao* is continuing her research on coral reefs and acidification on material available at San Diego Museum of Natural History.

John Klasik:

Technical guidance and supervision, X-ray Diffraction: Dr. Ravi and **five students from Materials Engineering*** (Composites Team, Corrosion Team)

Member, Master's Thesis Committee, **Mathew Willis***, Center for Regenerative Studies: Commenced June 2010

Assisted **several Geological Sciences students*** in their research/class-related X-ray Fluorescence studies.

Jeffrey Marshall:

Research Experience for Undergraduates (REU) & Senior Thesis Research: "Seismogenesis of the Middle America Trench at the Nicoya Peninsula over multiple seismic cycles" funded by the National Science Foundation MARGINS Program - Undergraduate Researchers: **Amber Butcher*, Sarah Denise*, Jazmín González*, Susana Lino*, Shawn Morrish*, Brent Ritzinger*, and Kacie Wellington*** (Geological Sciences Department)

Team research activities in 2010 related to this project included the following:

Península de Nicoya, Costa Rica, Central America: Field mapping, surveying, and sampling of uplifted marine and alluvial terraces & surveying of pre-earthquake tidal levels, Playa Carbón, Playa Grande, San Juanillo, Playa Garza, and Playa Coyote, with A. Butcher, S. Morrish, B. Ritzinger, and K. Wellington (Cal Poly Pomona undergraduate students) (March 7-25, 2010)
Summer and Fall 2010 laboratory and computer work at Cal Poly Pomona: Preparation and shipping of field samples for radiocarbon dating at Beta Analytic Labs and optically stimulated luminescence dating at University of Cincinnati; cutting thin section blanks; drafting geologic maps and generating digital elevation models of field sites; processing topographic survey data and generating elevation profiles of paleo-shorelines; interpreting field results; creating posters for presentation at professional meetings.
Team presentation of research results in posters at two professional conferences: 1) Joint Meeting of the Geological Society of America (GSA) Cordilleran Section and American Association of Petroleum Geologists (AAPG) Pacific Section, Anaheim, CA (May 27-29, 2010), and 2) American Geophysical Union (AGU) Fall Conference, San Francisco, CA (December 12-18, 2010)

Jonathan Nourse:

Investigation of the February 18, 2010 Landslide Along the Interstate 10- 57 Freeway Connector: Field work with Caltrans geologist Gustavo Orte-

ga and student assistants **Kelly Kinder*** and **Brent Ritzinger***.

Gravity measurements and Total Station surveying in the Poverty Hills, Owens Valley, California, assisted by **Kelly Kinder***, **Josh Sargent***, **Kyle Wright*** and **Celia Pazos***, April 16-18

Late Quaternary evolution of the Sierra Madre frontal Fault system, south-central San Gabriel Mountains, Field work related to USGS National Earthquake Hazards Reduction Program grant, assisted by **Jeff Pepin*** and **Audra Hanks***, January-December.

Senior Thesis students supervised during 2010: **Logan Wicks*, Melissa Bonner*, Andrew Kieta*, Audra Hanks*, Jeff Pepin*, Kelly Kinder*, Leonard Amurao*, Christina Bloom***

Jascha Polet:

Senior Thesis students supervised during 2010:

Brian Oliver*, A Pilot Study to Determine Shear-Wave Velocities for Earthquake Site Response at Cal Poly Pomona Campus using Refraction Micro-Tremor, senior thesis defended June 2010.

Kevin Kwong*, Testing an Algorithm to Rapidly Determine Earthquake Source Parameters From Aftershocks, senior thesis research started Fall 2010.

Celia Pazos*, Gravity Profiles Across the San Jose Fault on Cal Poly Pomona Campus, senior thesis research started Fall 2010.

Hannah Potter*, Gravity Profiles Across the San Jose Fault on Cal Poly Pomona Campus, senior thesis research started Fall 2010.

b. Presentations involving students as co-presenters

David Jessey:

Bruns*, J., and Jessey, D.R., 2010, Tectonic implications of basaltic volcanism in the Owens Valley, CA: Bulletin - Southern California Academy of Sciences, August 2010, Vol. 109, Issue 2

Bruns*, J., and Jessey, D.R., 2010, Neogene Basaltic Volcanism in the Southern Owens Valley, CA: Implications to Tectonics of the ECSZ: Abstracts with Programs - Geological Society of America, May 2010, Vol. 42, Issue 4.

John Klasik:

Klasik was not co-author of any student presentation. However several Materials Science students under his direction did give presentations using data collected in the Geological Sciences X-ray Diffraction Laboratory.

Jeffrey Marshall:

Marshall, J., **Morrish*, S., Butcher*, A., Ritzinger*, B., Wellington*, K., LaFromboise*, E.**, Protti, M., Gardner, T., and Spotila, J., 2010, Morphotectonic segmentation along the Nicoya Peninsula seismic gap, Costa Rica: Eos, Transactions, American Geophysical Union, v. 91, Fall Meeting Supplement, Abs. T11D-2138.

Spotila, J.A., Kennedy, L.M., **Durden*, A., Depew*, K., Smithka*, I., Cunningham*, C.**, Marshall, J.S., **Prince*, P.S., and Tranel*, L.M.**, 2010, Paleoseismic investigations of the Middle America Trench on the Nicoya Peninsula, Costa Rica: A feasibility study of the Tamarindo estuary: Geological Society of America, Abstracts with Programs, v. 42, no. 5, Abstract 250-3, p. 594. **[Note: These students from Virginia Tech]**

LaFromboise*, E., Marshall, J., Simila, G., Protti, M., and Quintero, R., 2010, Neotectonics of the Nicoya Peninsula, Costa Rica: Geological Society of America, Abstracts with Programs, v. 42, no. 4, p. 100, Abstract 48-12.

Morrish*, S.C., Butcher*, A.J., Ritzinger*, B.T., Wellington*, K.L., and Marshall, J.S., 2010, Tectonic geomorphology and earthquake hazards of the Nicoya Peninsula seismic gap, Costa Rica, Central America: Geological Society of America, Abstracts with Programs, v. 42, no. 4, p. 64, Abstract 18-25.

Jonathan Nourse:

Wicks*, L.E. and Nourse, J.A., 2010, Failure analysis of a rockslide on Sunset Ridge fire access road, San Gabriel Mountains, California, Senior Thesis, Cal Poly Pomona, 23 p, defended May 18

Bonnar*, M., and Nourse, J.A., 2010, Structural analysis of folded Paleoproterozoic gneiss near West Fork-North Fork San Gabriel River confluence, California, Geological Society of America Abstracts with Programs, Vol. 42, No. 4, p. 61.

Kieta*, A., and Nourse, J.A., 2010, Impacts of the floods of 1938, 1969 and 2005 on the Old Mt.

Baldy Road, San Gabriel Mountains, California, Geological Society of America Abstracts with Programs, Vol. 42, No. 4, p. 60.

Jascha Polet:

Kwong*, K., and Polet, J., 2010, The Use of Aftershocks to Rapidly Estimate Rupture Extent for Large Earthquakes, 18th annual meeting of the Southern California Conference for Undergraduate Research (SCCUR), Pepperdine University, Malibu, 2010.

3. Professional Awards and Honors

Jeffrey Marshall:

Elected by national membership of Council on Undergraduate Research (CUR) to third three-year term as CUR Councilor (Geosciences Division)

National Science Foundation (NSF) GeoPRISMS Program – Invited to serve as member of GeoPRISMS Education Advisory Committee (GEAC)

Invited Workshop Leader – On the Cutting Edge Geosciences Professional Development Program, Workshop for Graduate Students/Post-Docs: "Preparing for an Academic Career in the Geosciences", Stanford University, Palo Alto, CA (July 29 - Aug 1, 2010)

Invited Proposal Review Panelist – National Science Foundation (NSF) Tectonics Program (October 2010 - declined due to schedule conflict)

Jascha Polet:

Invited participant for the following workshops – "The Math You Need, When You Need It 2010: A workshop for faculty teaching introductory geoscience", "Using on-line volcano monitoring data in college and university courses: The Volcano Exploration Project: Pu`u `O`o (VEPP)" and "Geophysical Hazards and Plate Boundary Processes in Central America, Mexico and the Caribbean".

The Geological Sciences Department at Cal Poly Pomona is an official voting member of IRIS (Incorporate Research Institutions for Seismology). Membership benefits include: opportunities to participate in research grants and seismic experiments, access to seismic data sets, eligibility for student scholarships and internships, and access to employment networks for faculty and student job searches.

4. Professional Service and Public Outreach

Service to the Profession

Jeffrey Marshall:

Council on Undergraduate Research (CUR) Geosciences Division – Elected Councilor

NSF GeoPRISMS Program Education Advisory Committee (GEAC) – Member

Director of Grad Student/Post-Doc Program - NSF GeoPRISMS Program Subduction Cycles and Deformation (SCD) Implementation Workshop, Bastrop, TX (Jan 5-7, 2011)

Workshop Leader – On the Cutting Edge Geosciences Professional Development Program, Workshop for Graduate Students/Post-Docs: "Preparing for an Academic Career in the Geosciences", Stanford University, Palo Alto, CA (July 29 - Aug 1, 2010)

CSU SMART Team: State Disaster Mitigation Assessment Review Team – Member

National Science Foundation (NSF) Tectonics Program – Proposal Reviewer

National Science Foundation (NSF) Tectonics Program – Invited Proposal Review Panelist (Oct 2010, declined due to schedule conflict)

Student Abstract Reviewer – Society for Advancement of Chicanos and Native Americans in Science (SACNAS) National Conference, Anaheim, CA (October 2010)

Jonathan Nourse:

Session Chair – Geological Sciences of America Cordilleran Section Meeting, Logan, Utah (May 2011)

Reviewer – Geopsphere manuscript submission by Gonzalez Leon et al., April, 2011

Reviewer – Mexican journal Revista manuscript submission by Rascon-Heimpel et al., May, 2011

Jascha Polet:

Invited member – Four-person review panel of the USGS National Earthquake Hazard Program, 2010

Reviewer – For the following journals: Seismological Research Letters and Geophysical Research Letters.

Reviewer – National Science Foundation, Geo physics Program

Session Chair – "The Earthquake Source: Observations and Modeling", AGU Meeting of the Americas, Foz do Iguaçu, Brazil, 2010.

Service to the Greater Community

Jeffrey Marshall:

California State University San Marcos, Office of Research & Committee on Undergraduate Research – Program Reviewer

Earth Science Content Specialist – San Gabriel Valley Science Project Workshop for Elementary School Teachers, CEEMaST, Cal Poly Pomona (June 22-24, 2011)

Earth Science Content Specialist – NASA LiftOff Science Education Program for High School Teachers, Los Angeles County Department of Education & Cal Poly Pomona College of Science (June 28-July 2, 2010 and August 2-6, 2010, plus follow-up activities throughout 2010-11)

Visiting Scientist – Sycamore Elementary School, Claremont, California, Room 12, Grades 2-3 (December 10, 2010)

Participant – Thompson Creek Restoration Plan Community Meeting, Claremont League of Women Voters, Hughes Community Center, Claremont, CA (September 25, 2010)

Whittier College Environmental Sciences Department-salvage and retrieval of valuable Geology laboratory equipment, teaching collections and library archives, June 2011

Attachments

Here are a couple recent articles by Dr. Marshall and Dr. Osborn to give you a sense of what they have been doing

Piedras de Fuego and the Trembling Serpent of Nicoya: On the hunt for ancient shorelines and megathrust earthquakes

Nicoya Peninsula, Costa Rica

Jeff Marshall (Cal Poly Pomona) and Jim Spotila (Virginia Tech)

This is the first in a series of field blogs, to inform the community of real-time, exciting GeoPRISMS research. If you would like to contribute to this series, please contact the GeoPRISMS office at info@geoprisms.org

8 March 2011 – Playa Sámara, Guanacaste

Greetings from atop the Nicoya Peninsula seismogenic zone in Costa Rica! We write to you from our beachside table at a popular tavern on Playa Sámara, a fine spot to chill out after a productive day of gritty fieldwork beneath the sweltering Nicoya sun. We are here engaged in our second NSF MARGINS field expedition examining the neotectonics and paleoseismology of the northern Costa Rica fore arc. This project is funded by a collaborative grant entitled: "Seismogenesis of the Middle America Trench at the Nicoya Peninsula over multiple seismic cycles". Jeff Marshall (Cal Poly Pomona) and his students are studying uplifted paleoshorelines to constrain spatially variable patterns of long-term deformation along the Nicoya coast. Jim Spotila (Virginia Tech) and his students are coring coastal estuaries in search of stratigraphic evidence for short-term seismic cycle displacements.

Our joint fieldwork this week focuses on the central Nicoya coast within the area of maximum uplift associated with the seismogenic zone. Our all-star crew includes field savvy grad students Shawn Morrish (Cal Poly Pomona) and Phil Prince (Virginia Tech), as well as geochronology guru Lewis Owen and his post-doc Madhav Murari (U. Cincinnati). Today, we split into two teams, one group seeking datable deposits on river terraces near the coast, and the other exploring coastal wetlands for new coring sites.

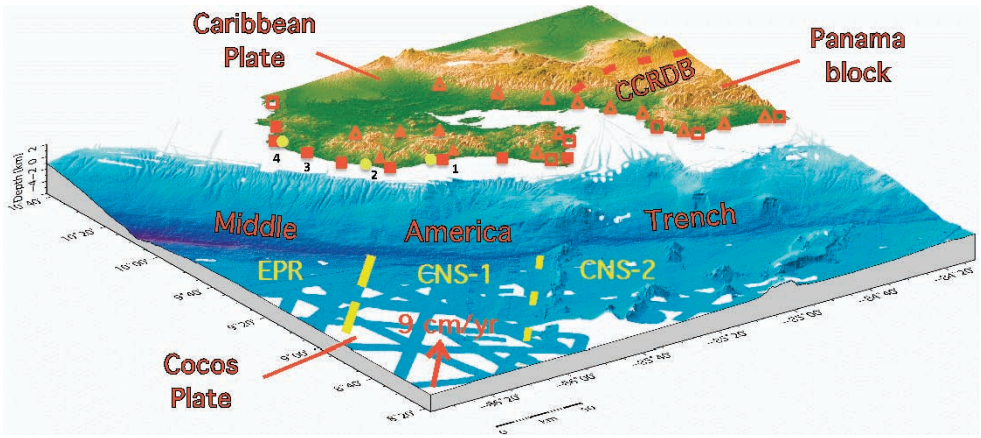


Figure 1. DEM of the northern Costa Rica convergent margin showing primary field sites for this NSF MARGINS project (solid symbols), and prior study sites from related projects (open symbols). Focus of research at each site indicated by symbol shape: marine terraces (squares), river terraces (triangles), and paleoseismic coring (circles). Numbers indicate sites discussed in this article: 1) Puerto Carrillo and Río Ora Valley; 2) Boca Nosara and Punta Peladas; 3) Playa Junquillal and Playa Negra; 4) Tamarindo Estuary. Variations in neotectonic deformation and seismogenesis along the Costa Rica margin are related to three contrasting domains of subducting seafloor offshore: EPR, CNS-1, and CNS-2. (DEM courtesy of C.J. Petersen, IFM-GEOMAR).

The Terrace Team (Marshall, Morrish, Owen, and Murari) headed up the Río Ora Valley inland of Puerto Carrillo to collect samples for ^{10}Be cosmogenic radionuclide dating of radiolarian chert boulders stranded on the surface of late Pleistocene river terraces. These huge bright red boulders are a distinctive feature of the local landscape. Eroded out of oceanic basement rocks in the nearby hills (Cretaceous Nicoya Complex), these boulders were transported downstream by the river and deposited along flood plain terraces. These terraces have undergone progressive uplift and now lie 40 meters above the modern incised channel of the Río Ora. Lewis assures me that the chert has strong potential for revealing the boulder ages, thus allowing us to determine rates of river incision and terrace uplift.

Figure 2. ƀ ² ŜŭtI·yŘ ¢ŜI·YƀŘdzNƛyƎ tI·ăŭ ěŜI·NƛăăŘ ŦƛŜtŘ ŜĚLJŜŘπ ŭƛ2Y YŜI·ădzNƛyƎ LJI·tŜ2ăŜƛăYƛŎ ăŜŘƛYŜyŭ ŏ2NƛŜ ŜĚúNƛI·ŏŭŜŘ ŦNƛ2Y I· YI·yƎNƛ2ØŜ ŭƛŘI·t ŦtI·ŭΣ ¢I·YI·NƛπƛyŘ2 9ăŭdzI·NƛěΦ [ŜŦŭ ŭ2 wƛƎKŭY !těăăI· 5dzNƛŘŜyΣ YŜƛŭK 5ŜtŜØΣ /NƛI·ƛƎ /dzyŷƛyƎKI·Y ó±ƛNƛƎƛyƛI· ¢ŜŎKú.

The shrill ping of our hammers chipping away at the brutally hard chert inspired a few loud protests from Howler Monkeys congregated in trees just across the river. The commotion also caught the attention of a few large Brahma bulls in surrounding fields. Fortunately, they were more interested in cavorting with the cows than chasing us away. Our noisy pursuits also raised the curiosity of local residents in nearby ranch houses. One kind old "sabanero" who came out to investigate told us that the locals refer to these boulders as "Piedras de Fuego" or "Stones of Fire". He said that the Chorotega people who once inhabited this valley believed the stones were a source of powerful mystic

C λ∃dzNŜ oI·πŎΦ !Y ¢KŜ "Terrace Team" sampling radiolarian chert boulders for ^{10}Be exposure I·∃Ŝ dating of late Pleistocene river terraceă, Río Ora Valley. [Ŝ†ŭ ŭ2 wλ∃Kŭ: Madhav Murari ó ¦ Φ /λyŎλyŕnati), Shawn Morrish (Cal Poly Pomona)Σ Lewis Owen (U. Cincinnati). . : Shawn a 2NNNλăKΣ Kelly Kinder, I·yŘ Andrew Barnhart (Cal Poly Pomona) sample basalt from marine ŭŜNNNI·ŎŜ tread for ^{36}Cl exposure age dating, Playa Negra. /: MARGINS REU "Team bλŎ2ěI·þ I·ŭ ŭKŜ ŎNI·ŭŜN of Volcán Póas. LŜ†ŭ to Rλ∃Kŭ: Jeff Marshall (P.I.), Andrew Barnhart, Amber Butπ ŎKŜNΣ YŜffě Kinder, Shawn Morrish, Brent Ritzinger, Kacie Wellington (/I·f t2fě t2Y2yI·).

energy. At a minimum, we hope that they preserve a measurable signal of radionuclide decay.

While the Terrace Team sampled boulders, the Wetland Team (Spotila and Prince) scouted nearby estuaries, searching for potential coring sites that might reveal records of seismic cycle displacements. Despite the impressive jaws of a 5-foot long crocodile patrolling the mouth of the Carrillo estuary, Jim and Phil donned their waders and bravely slogged out into the muddy mangrove swamp. At one site, they uncovered some intriguing peat horizons separating sharp contrasts in sediment grain size. Radiocarbon dating and facies analysis will hopefully reveal if these strata are earthquake related. Similar coring studies last year focused on the northern Nicoya Peninsula within an area of low net uplift (Tamarindo Estuary). That work revealed sedimentation rates that are too slow to preserve adequate paleoseismic records. This year we are targeting wetlands along the central coast within areas of faster net uplift and presumably greater coseismic displacements. If the crocodiles permit, we hope to extract some useful data on past earthquakes.

11 March 2011 – Boca Nosara, Guanacaste

We gather around morning coffee, only to learn that a Magnitude 8.9 earthquake has ruptured the northern subduction zone of Japan, spawning a destructive tsunami. For a team of nerdy field geologists, armed with laptops, iPads, and a sketchy wireless connection, this quickly devolves into a tap-and-click competition to access the best seismic data, tsunami models, and real-time disaster videos. We soon begin to appreciate the magnitude of this destructive event. From one subduction zone to another, our thoughts reach out to the people of Japan.

The hotel owner tells us that the local emergency commission has issued a tsunami alert with waves from Japan expected to arrive on the Nicoya Peninsula in the late afternoon. Despite this warning, we head out for fieldwork along the coast. Jim and Phil descend into the Río Nosara wetlands for more paleoseismic coring, while Jeff, Shawn, Lewis, and Madhav hike out along the beach at Punta Peladas in search of terrace sampling sites. "Hmmm, interesting how empty the beach is today!" We are emboldened by the tsunami models we saw online that show a 4:15 pm arrival time for a relatively small wave. Oh, savor the irony, field geologists entrusting their lives to geophysicists! We can see the headlines now: "Six geologists swept out to sea. Geophysicists apologize for modeling error." Yes indeed, this is interdisciplinary plate margins science in action!

At the appointed hour, we return to the "Sunset Bar" at our hotel, perched on the cliff top at Boca Nosara, 40 meters above the beach. This hotel is the officially designated disaster evacuation site for the local community. A crowd begins to gather, tourists and townspeople

mingling and waiting with great anticipation to watch the spectacle. It's "Tsunami Hour" here at the Sunset Bar!

With digital cameras in hand, smart phones buzzing, and wireless laptops glowing with imagery, we read of tsunami impacts around the Pacific basin - Japan, Hawaii, California, and Mexico. Now breaking news from Nicaragua tells of ongoing evacuations along the low-lying coast. And, here at the Sunset Bar in Nosara, gringo turistas jabber and clink bottles, Tica moms chase after their squawking kids, and a group of grungy geologists speak in low authoritative tones of tsunami wavelengths, celerity, and run-up. Everyone watches the horizon.

Then, at 4:15 pm, the predicted time of wave arrival, nothing much happens. Well, yes, we think that maybe there was a bit more movement in the water, wider wave crests perhaps, and the run-up, well, maybe it seemed a little higher. But, all in all, nothing remarkable happens. Sunset proceeds as normal toward the celebrated green flash, fisherman still work the river mouth as the tide floods the estuary, and the Sunset Bar gradually empties as the crowd disperses for dinner. Apparently, at least for now, we dodged a bullet here on the other side of the pond. But, silently, all along the Nicoya coast, the ground ever so slowly continues to subside, the tides cut inland a bit further, and the peninsula accumulates more strain energy, waiting its turn to jump-up and shake.

16 March 2011 – Playa Junquillal, Guanacaste

Greetings from another cliff top perch along the Nicoya Peninsula! The sun is setting as another excellent field day comes to an end. This time, we are at Playa Junquillal, up north where the cliffs are shorter and the first marine terrace lies at half the elevation it has at our prior locations. Our colleagues from Virginia Tech and Cincinnati have flown home to the US, and five more geology majors from Cal Poly Pomona have joined Jeff and Shawn for a second week of fieldwork focused on terrace mapping, sampling, and surveying.

The new members of Team Nicoya are Andrew Barnhart, Amber Butcher, Kelly Kinder, Brent Ritzinger, and Kacie Wellington. These undergraduate students are participants in the REU program supported by our MARGINS grant. Each student is working on a senior thesis focused on one of a series of field sites along the Nicoya coast. These individual projects each contribute a separate piece to the overall research puzzle. Our MARGINS supported fieldwork, both this year and last, builds upon several decades of prior neotectonics research on the Nicoya Peninsula. Together, these studies have documented significant variations in net Quaternary uplift along the Nicoya coastline. On a first order, these variations appear to be related to along-strike differences in the subducting seafloor and seismogenic zone observed by other MARGINS scientists.

Our fieldwork today, took us first to Playa Negra, a world-famous surfing beach featured in the classic cult film *Endless Summer II*. Our goal was to sample basalt outcrops along the cliff edge for ^{36}Cl exposure age dating of the first marine terrace tread. As we plodded across the beach with field packs, rock hammers, and hiking boots, we generated some curiosity among surfers and sunbathers. "Hey, are you guys like scientists or something?" "Totally, dude." Having learned the drill yesterday on outcrops near our hotel, the students performed like a well-oiled machine, chipping out samples, labeling sample bags, taking notes, measuring cliff heights, and recording GPS coordinates. And, most significantly, they lugged all the samples and gear back to our vehicles! Yes, it's nice to be in charge.

Leaving Playa Negra, we drove inland on rocky ranch roads to a wooded area on the second marine terrace where we had seen more of the red chert boulders. Again, the students jumped into action, sampling five of the Stones of Fire with stunning efficiency. If only I can get them to write-up their research reports with such blinding speed! I think it was helpful to entice them with an incentive of cool beverages and lunch in the shade at a favorite eatery up the road. As we left the field with our samples in hand, we stumbled upon a remarkable 6-foot long snakeskin stretched across the ground. We were quite glad we discovered this only as we were leaving the field! I'm sure the beast that left the skin was not far away.

A popular Chorotega legend tells of a giant trembling serpent that lives deep within the rugged mountains of the Nicoya Peninsula. When provoked, this angry creature links its tail with a similar monster beneath Laguna de Apoyo in Nicaragua, and the two serpents thrash about causing violent shaking of the earth. During the colonial era, Spanish priests began leading an annual pilgrimage to a prominent Nicoya hilltop to plant crosses and calm the angry serpent. This practice continues to this day, with a yearly ritual held each 3rd of May on the summit of Cerro las Cruces. Despite the good intentions of such an earthquake mitigation strategy, large temblors still rock the Nicoya Peninsula several times each century.

The last major rupture of the Nicoya seismogenic zone (M 7.7) struck the peninsula on 5 October 1950. This event killed and injured dozens of people, severely damaged buildings and roads, and produced landslides, liquefaction, and abrupt coseismic coastal uplift. Beach residents and fishermen describe a sudden retreat of the ocean that exposed submerged headlands and broad areas of the rocky intertidal platform. During subsequent decades, the tides slowly reclaimed this area and waves now reach further inland than before the 1950 earthquake. High tides routinely inundate parts of the coastline, washing over roads, undermining trees, and sweeping into beachside homes and tourist hangouts. Such changes are apparent all along the central Nicoya coast as the shoreline gradually subsides and strain builds toward the next earthquake. Despite the impending hazard, this beautiful region has become an epicenter for rapid coastal development driven by Costa Rica's world-renowned tourism trade. Construction of hotels, condominiums, and vacation homes proceeds without heed for the lurking earthquake hazard.

It is critical therefore, that geoscientists, government officials, and local residents develop a better understanding of the megathrust earthquake cycle beneath the Nicoya Peninsula. We hope to contribute to this understanding by defining patterns of both short-term seismic cycle motions, as well as long-term net deformation along the Nicoya seismogenic zone.

Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing

Stephen G. Osborn[a], Avner Vengosh[b], Nathaniel R. Warner[b], and Robert B. Jackson[a,b,c,1]

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Edited* by William H. Schlesinger, Cary Institute of Ecosystem Studies, Millbrook, NY, and approved April 14, 2011 (received for review January 13, 2011)

Directional drilling and hydraulic-fracturing technologies are dramatically increasing natural-gas extraction. In aquifers overlying the Marcellus and Utica shale formations of northeastern Pennsylvania and upstate New York, we document systematic evidence for methane contamination of drinking water associated with shale-gas extraction. In active gas-extraction areas (one or more gas wells within 1 km), average and maximum methane concentrations in drinking-water wells increased with proximity to the nearest gas well and were 19.2 and 64 mg CH_4 L^{-1} ($n = 26$), a potential explosion hazard; in contrast, dissolved methane samples in neighboring nonextraction sites (no gas wells within 1 km) within similar geologic formations and hydrogeologic regimes averaged only 1.1 mg L^{-1} ($P < 0.05$; $n = 34$). Average $\delta^{13}C$-CH_4 values of dissolved methane in shallow groundwater were significantly less negative for active than for nonactive sites (-37 ± 7‰ and -54 ± 11‰, respectively; $P < 0.0001$). These $\delta^{13}C$-CH_4 data, coupled with the ratios of methane-to-higher-chain hydrocarbons, and $\delta^{2}H$-CH_4 values, are consistent with deeper thermogenic methane sources such as the Marcellus and Utica shales at the active sites and matched gas geochemistry from gas wells nearby. In contrast, lower-concentration samples from shallow groundwater at nonactive sites had isotopic signatures reflecting a more biogenic or mixed biogenic/thermogenic methane source. We found no evidence for contamination of drinking-water samples with deep saline brines or fracturing fluids. We conclude that greater stewardship, data, and—possibly—regulation are needed to ensure the sustainable future of shale-gas extraction and to improve public confidence in its use.

groundwater | organic-rich shale | isotopes | formation waters | water chemistry

Increases in natural-gas extraction are being driven by rising energy demands, mandates for cleaner burning fuels, and the economics of energy use (1–5). Directional drilling and hydraulic-fracturing technologies are allowing expanded natural-gas extraction from organic-rich shales in the United States and elsewhere (2, 3). Accompanying the benefits of such extraction (6, 7) are public concerns about drinking-water contamination from drilling and hydraulic fracturing that are ubiquitous but lack a strong scientific foundation. In this paper, we evaluate the potential impacts associated with gas-well drilling and fracturing on shallow groundwater systems of the Catskill and Lockhaven formations that overlie the Marcellus Shale in Pennsylvania and the Genesee Group that overlies the Utica Shale in New York (Figs. 1 and 2 and Fig. S1). Our results show evidence for methane contamination of shallow drinking-water systems in at least three areas of the region and suggest important environmental risks accompanying shale-gas exploration worldwide.

The drilling of organic-rich shales, typically of Upper Devonian to Ordovician age, in Pennsylvania, New York, and elsewhere in the Appalachian Basin is spreading rapidly, raising concerns for impacts on water resources (8, 9). In Susquehanna County, Pennsylvania alone, approved gas-well permits in the Marcellus formation increased 27-fold from 2007 to 2009 (10).

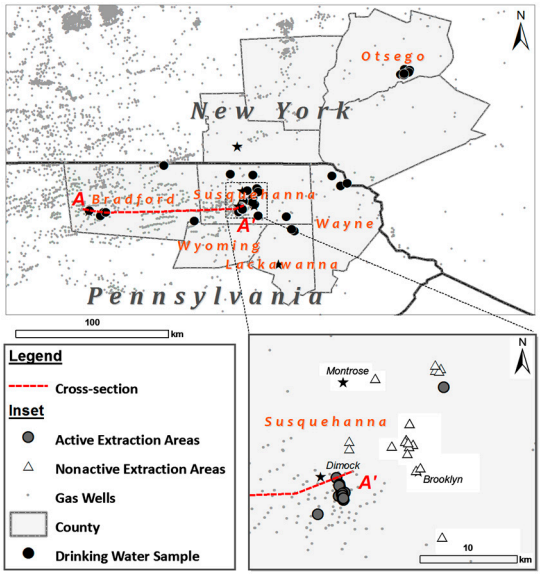

Fig. 1. Map of drilling operations and well-water sampling locations in Pennsylvania and New York. The star represents the location of Binghamton, New York. (*Inset*) A close-up in Susquehanna County, Pennsylvania, showing areas of active (closed circles) or nonactive (open triangles) extraction. A drinking-water well is classified as being in an active extraction area if a gas well is within 1 km (see *Methods*). Note that drilling has already spread to the area around Brooklyn, Pennsylvania, primarily a nonactive location at the time of our sampling (see inset). The stars in the inset represent the towns of Dimock, Brooklyn, and Montrose, Pennsylvania.

Concerns for impacts to groundwater resources are based on (*i*) fluid (water and gas) flow and discharge to shallow aquifers due to the high pressure of the injected fracturing fluids in the gas wells (10); (*ii*) the toxicity and radioactivity of produced water from a mixture of fracturing fluids and deep saline formation waters that may discharge to the environment (11); (*iii*) the potential explosion and asphyxiation hazard of natural gas; and (*iv*) the large number of private wells in rural areas that rely on shallow groundwater for household and agricultural use—up to one million wells in Pennsylvania alone—that are typically unregulated and untested (8, 9, 12). In this study, we analyzed groundwater from 68 private water wells from 36- to 190-m deep in

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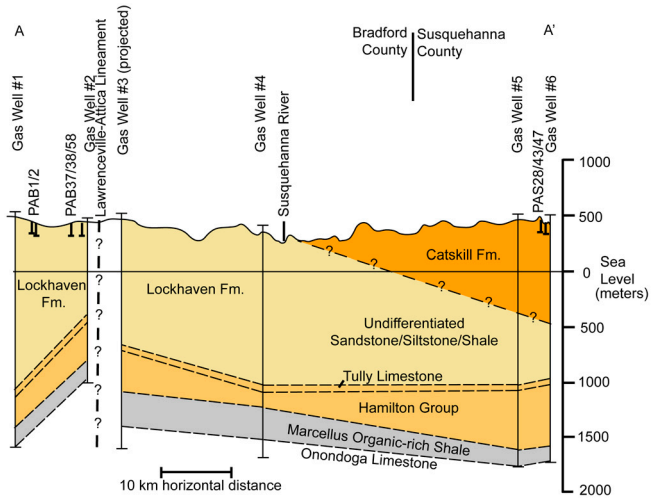

Fig. 2. Geologic cross-section of Bradford and western Susquehanna Counties created from gas-well log data provided by the Pennsylvania Department of Conservation and Natural Resources. The approximate location of the Lawrenceville-Attica Lineament is taken from Alexander et al. (34). The Ordovician Utica organic-rich shale (not depicted in the figure) underlies the Middle Devonian Marcellus at approximately 3,500 m below the ground surface.

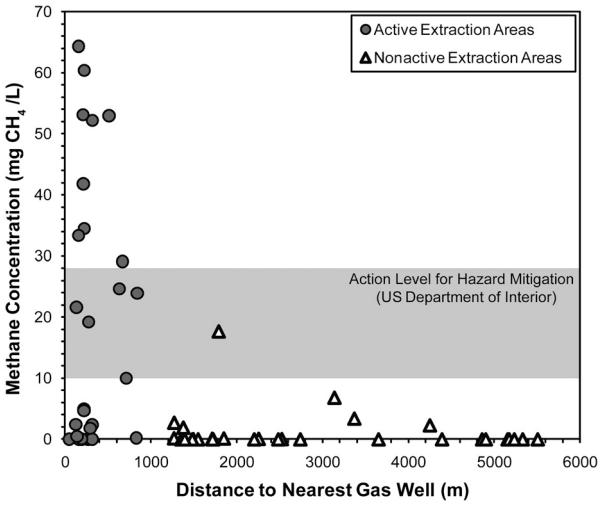

Fig. 3. Methane concentrations (milligrams of CH_4 L^{-1}) as a function of distance to the nearest gas well from active (closed circles) and nonactive (open triangles) drilling areas. Note that the distance estimate is an upper limit and does not take into account the direction or extent of horizontal drilling underground, which would decrease the estimated distances to some extraction activities. The precise locations of natural-gas wells were obtained from the Pennsylvania Department of Environmental Protection and Pennsylvania Spatial Data Access databases (ref. 35; accessed Sept. 24, 2010).

northeast Pennsylvania (Catskill and Lockhaven formations) and upstate New York (Genesee formation) (see Figs. 1 and 2 and *SI Text*), including measurements of dissolved salts, water isotopes (^{18}O and ^{2}H), and isotopes of dissolved constituents (carbon, boron, and radium). Of the 68 wells, 60 were also analyzed for dissolved-gas concentrations of methane and higher-chain hydrocarbons and for carbon and hydrogen isotope ratios of methane. Although dissolved methane in drinking water is not currently classified as a health hazard for ingestion, it is an asphyxiant in enclosed spaces and an explosion and fire hazard (8). This study seeks to evaluate the potential impact of gas drilling and hydraulic fracturing on shallow groundwater quality by comparing areas that are currently exploited for gas (defined as active—one or more gas wells within 1 km) to those that are not currently associated with gas drilling (nonactive; no gas wells within 1 km), many of which are slated for drilling in the near future.

Results and Discussion

Methane concentrations were detected generally in 51 of 60 drinking-water wells (85%) across the region, regardless of gas industry operations, but concentrations were substantially higher closer to natural-gas wells (Fig. 3). Methane concentrations were 17-times higher on average (19.2 mg CH_4 L^{-1}) in shallow wells from active drilling and extraction areas than in wells from nonactive areas (1.1 mg L^{-1} on average; $P < 0.05$; Fig. 3 and Table 1). The *average* methane concentration in shallow groundwater in active drilling areas fell within the defined action level (10–28 mg L^{-1}) for hazard mitigation recommended by the US Office of the Interior (13), and our maximum observed value of 64 mg L^{-1} is well above this hazard level (Fig. 3). Understanding the origin of this methane, whether it is shallower biogenic or deeper thermogenic gas, is therefore important for identifying the source of contamination in shallow groundwater systems.

The $\delta^{13}C$-CH_4 and $\delta^{2}H$-CH_4 values and the ratio of methane to higher-chain hydrocarbons (ethane, propane, and butane) can typically be used to differentiate shallower, biologically derived methane from deeper physically derived thermogenic methane (14). Values of $\delta^{13}C$-CH_4 less negative than approximately −50‰ are indicative of deeper thermogenic methane, whereas values more negative than −64‰ are strongly indicative of microbial methane (14). Likewise, $\delta^{2}H$-CH_4 values more negative than about −175‰, particularly when combined with low $\delta^{13}C$-CH_4 values, often represent a purer biogenic methane origin (14).

The average $\delta^{13}C$-CH_4 value in shallow groundwater in active drilling areas was -37 ± 7‰, consistent with a deeper thermogenic methane source. In contrast, groundwater from nonactive areas in the same aquifers had much lower methane concentrations and significantly lower $\delta^{13}C$-CH_4 values (average of −54± 11‰; $P < 0.0001$; Fig. 4 and Table 1). Both our $\delta^{13}C$-CH_4 data and $\delta^{2}H$-CH_4 data (see Fig. S2) are consistent with a deeper thermogenic methane source at the active sites and a more biogenic or mixed methane source for the lower-concentration samples from nonactive sites (based on the definition of Schoell, ref. 14).

Because ethane and propane are generally not coproduced during microbial methanogenesis, the presence of higher-chain hydrocarbons at relatively low methane-to-ethane ratios (less than approximately 100) is often used as another indicator of deeper thermogenic gas (14, 15). Ethane and other higher-chain hydrocarbons were detected in only 3 of 34 drinking-water wells from nonactive drilling sites. In contrast, ethane was detected in 21 of 26 drinking-water wells in active drilling sites. Additionally, propane and butane were detected (>0.001 mol %) in eight and two well samples, respectively, from active drilling areas but in no wells from nonactive areas.

Further evidence for the difference between methane from water wells near active drilling sites and neighboring nonactive sites is the relationship of methane concentration to $\delta^{13}C$-CH_4 values (Fig. 4*A*) and the ratios of methane to higher-chain hydro-

Table 1. Mean values ± standard deviation **of methane concentrations (as milligrams of CH_4 L^{-1}) and carbon isotope composition in methane in shallow groundwater $\delta^{13}C$-CH_4 sorted by aquifers and proximity to gas wells (active vs. nonactive)**

Water source, *n*	milligrams CH_4 L^{-1}	$\delta^{13}C$-CH_4, ‰
Nonactive Catskill, 5	1.9 ± 6.3	−52.5 ± 7.5
Active Catskill, 13	26.8 ± 30.3	−33.5 ± 3.5
Nonactive Genesee, 8	1.5 ± 3.0	−57.5 ± 9.5
Active Genesee, 1	0.3	−34.1
Active Lockhaven, 7	50.4 ± 36.1	−40.7 ± 6.7
Total active wells, 21	19.2	−37 ± 7
Total nonactive wells, 13	1.1	−54 ± 11

The variable *n* refers to the number of samples.

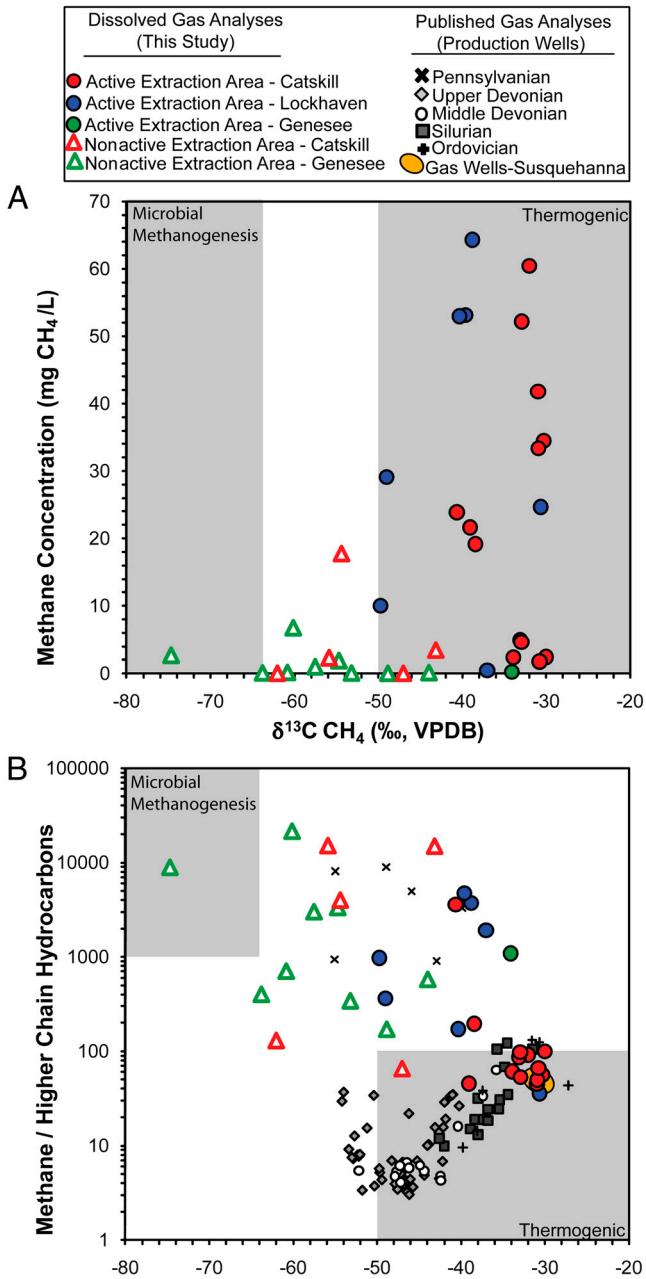

Fig. 4. (*A*) Methane concentrations in groundwater versus the carbon isotope values of methane. The nonactive and active data depicted in Fig. 3 are subdivided based on the host aquifer to illustrate that the methane concentrations and δ^{13}C values increase with proximity to natural-gas well drilling regardless of aquifer formation. Gray areas represent the typical range of thermogenic and biogenic methane taken from Osborn and Mcintosh (18). VPDB, Vienna Pee Dee belemnite. (*B*) Bernard plot (15) of the ratio of methane to higher-chain hydrocarbons versus the δ^{13}C of methane. The smaller symbols in grayscale are from published gas-well samples from gas production across the region (16–18). These data generally plot along a trajectory related to reservoir age and thermal maturity (Upper Devonian through Ordovician; see text for additional details). The gas-well data in the orange ovals are from gas wells in our study area in Susquehanna County, Pennsylvania (data from Pennsylvania Department of Environmental Protection). Gray areas represent typical ranges of thermogenic and biogenic methane (data from Osborn and McIntosh, ref. 18).

carbons versus δ^{13}C-CH_4 (Fig. 4*B*). Methane concentrations not only increased in proximity to gas wells (Fig. 3), the accompanying δ^{13}C-CH_4 values also reflected an increasingly thermogenic methane source (Fig. 4*A*).

Using a Bernard plot (15) for analysis (Fig. 4*B*), the enriched δ^{13}C-CH_4 (approximately $> -50‰$) values accompanied by low ratios of methane to higher-chain hydrocarbons (less than approximately 100) in drinking-water wells also suggest that dissolved gas is more thermogenic at active than at nonactive sites (Fig. 4*B*). For instance, 12 dissolved-gas samples at active drilling sites fell along a regional gas trajectory that increases with reservoir age and thermal maturity of organic matter, with samples from Susquehanna County, Pennsylvania specifically matching natural-gas geochemistry from local gas wells (Fig. 4*B*, orange oval). These 12 samples and local natural-gas samples are consistent with gas sourced from thermally mature organic matter of Middle Devonian and older depositional ages often found in Marcellus Shale from approximately 2,000 m below the surface in the northern Appalachian Basin (14–19) (Fig. 4*B*). In contrast, none of the methane samples from nonactive drilling areas fell upon this trajectory (Fig. 4*B*); eight dissolved-gas samples in Fig. 4*B* from active drilling areas and all of the values from nonactive areas may instead be interpreted as mixed biogenic/thermogenic gas (18) or, as Laughrey and Baldassare (17) proposed for their Pennsylvanian gas data (Fig. 4*B*), the early migration of wet thermogenic gases with low-δ^{13}C-CH_4 values and high methane-to-higher-chain hydrocarbon ratios. One data point from a nonactive area in New York fell squarely in the parameters of a strictly biogenic source as defined by Schoell (14) (Fig. 4*B*, upper-left corner).

Carbon isotopes of dissolved inorganic carbon (δ^{13}C-DIC $> +10‰$) and the positive correlation of δ^2H of water and δ^2H of methane have been used as strong indicators of microbial methane, further constraining the source of methane in shallow groundwater (depth less than 550 m) (18, 20). Our δ^{13}C-DIC values were fairly negative and show no association with the δ^{13}C-CH_4 values (Fig. S3), which is not what would be expected if methanogenesis were occurring locally in the shallow aquifers. Instead, the δ^{13}C-DIC values from the shallow aquifers plot within a narrow range typical for shallow recharge waters, with the dissolution of CO_2 produced by respiration as water passes downward through the soil critical zone. Importantly, these values do not indicate extensive microbial methanogenesis or sulfate reduction. The data do suggest gas-phase transport of methane upward to the shallow groundwater zones sampled for this study (<190 m) and dissolution into shallow recharge waters locally. Additionally, there was no positive correlation between the δ^2H values of methane and δ^2H of water (Fig. S4), indicating that microbial methane derived in this shallow zone is negligible. Overall, the combined gas and formation-water results indicate that thermogenic gas from thermally mature organic matter of Middle Devonian and older depositional ages is the most likely source of the high methane concentrations observed in the shallow water wells from active extraction sites.

A different potential source of shallow groundwater contamination associated with gas drilling and hydraulic fracturing is the introduction of hypersaline formation brines and/or fracturing fluids. The average depth range of drinking-water wells in northeastern Pennsylvania is from 60 to 90 m (12), making the average vertical separation between drinking-water wells and the Marcellus Shale in our study area between approximately 900 and 1,800 m (Fig. 2). The research area, however, is located in tectonically active areas with mapped faults, earthquakes, and lineament features (Fig. 2 and Fig. S1). The Marcellus formation also contains two major sets of joints (21) that could be conduits for directed pressurized fluid flow. Typical fracturing activities in the Marcellus involve the injection of approximately 13–19 million liters of water per well (22) at pressures of up to 69,000 kPa. The majority of this fracturing water typically stays underground and could in principle displace deep formation water upward into shallow aquifers. Such deep formation waters often have high concentrations of total dissolved solids >250,000 mg L^{-1}, trace

toxic elements, (18), and naturally occurring radioactive materials, with activities as high as 16,000 picocuries per liter (1 pCi L^{-1} = 0.037 becquerels per liter) for ^{226}Ra compared to a drinking-water standard of 5 pCi L^{-1} for combined ^{226}Ra and ^{226}Ra (23).

We evaluated the hydrochemistry of our 68 drinking-water wells and compared these data to historical data of 124 wells in the Catskill and Lockhaven aquifers (24, 25). We used three types of indicators for potential mixing with brines and/or saline fracturing fluids: (*i*) major inorganic chemicals; (*ii*) stable isotope signatures of water ($\delta^{18}O$, $\delta^{2}H$); and (*iii*) isotopes of dissolved constituents ($\delta^{13}C$-DIC, $\delta^{11}B$, and ^{226}Ra). Based on our data (Table 2), we found no evidence for contamination of the shallow wells near active drilling sites from deep brines and/or fracturing fluids. All of the Na^{+}, Cl^{-}, Ca^{2+}, and DIC concentrations in wells from active drilling areas were consistent with the baseline historical data, and none of the shallow wells from active drilling areas had either chloride concentrations >60 mg L^{-1} or Na-Ca-Cl compositions that mirrored deeper formation waters (Table 2). Furthermore, the mean isotopic values of $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$-DIC, $\delta^{11}B$, and ^{226}Ra in active and nonactive areas were indistinguishable. The ^{226}Ra values were consistent with available historical data (25), and the composition of $\delta^{18}O$ and $\delta^{2}H$ in the well-water appeared to be of modern meteoric origin for Pennsylvania (26) (Table 2 and Fig. S5). In sum, the geochemical and isotopic features for water we measured in the shallow wells from both active and nonactive areas are consistent with historical data and inconsistent with contamination from mixing Marcellus Shale formation water or saline fracturing fluids (Table 2).

There are at least three possible mechanisms for fluid migration into the shallow drinking-water aquifers that could help explain the increased methane concentrations we observed near gas wells (Fig. 3). The first is physical displacement of gas-rich deep solutions from the target formation. Given the lithostatic and hydrostatic pressures for 1–2 km of overlying geological strata, and our results that appear to rule out the rapid movement of deep brines to near the surface, we believe that this mechanism is unlikely. A second mechanism is leaky gas-well casings (e.g., refs. 27 and 28). Such leaks could occur at hundreds of meters underground, with methane passing laterally and vertically through fracture systems. The third mechanism is that the process of hydraulic fracturing generates new fractures or enlarges existing ones above the target shale formation, increasing the connectivity of the fracture system. The reduced pressure following the fracturing activities could release methane in solution, leading to methane exsolving rapidly from solution (29), allowing methane gas to potentially migrate upward through the fracture system.

Methane migration through the 1- to 2-km-thick geological formations that overlie the Marcellus and Utica shales is less likely as a mechanism for methane contamination than leaky well casings, but might be possible due to both the extensive fracture systems reported for these formations and the many older, uncased wells drilled and abandoned over the last century and a half in Pennsylvania and New York. The hydraulic conductivity in the overlying Catskill and Lockhaven aquifers is controlled by a secondary fracture system (30), with several major faults and lineaments in the research area (Fig. 2 and Fig. S1). Consequently, the high methane concentrations with distinct positive $\delta^{13}C$-CH_4 and $\delta^{2}H$-CH_4 values in the shallow groundwater from active areas could in principle reflect the transport of a deep methane source associated with gas drilling and hydraulic-fracturing activities. In contrast, the low-level methane migration to the surface groundwater aquifers, as observed in the nonactive areas, is likely a natural phenomenon (e.g., ref. 31). Previous studies have shown that naturally occurring methane in shallow aquifers is typically associated with a relatively strong biogenic signature indicated by depleted $\delta^{13}C$-CH_4 and $\delta^{2}H$-CH_4 compositions (32) coupled with high ratios of methane to higher-chain hydrocarbons (33), as we observed in Fig. 4*B*. Several models have been developed to explain the relatively common phenomenon of rapid vertical transport of gases (Rn, CH_4, and CO_2) from depth to the surface (e.g., ref. 31), including pressure-driven continuous gas-phase flow through dry or water-saturated fractures and density-driven buoyancy of gas microbubbles in aquifers and water-filled fractures (31). More research is needed across this and other regions to determine the mechanism(s) controlling the higher methane concentrations we observed.

Based on our groundwater results and the litigious nature of shale-gas extraction, we believe that long-term, coordinated sampling and monitoring of industry and private homeowners is needed. Compared to other forms of fossil-fuel extraction, hydraulic fracturing is relatively poorly regulated at the federal level. Fracturing wastes are not regulated as a hazardous waste under the Resource Conservation and Recovery Act, fracturing wells are not covered under the Safe Drinking Water Act, and only recently has the Environmental Protection Agency asked fracturing

Table 2. Comparisons of selected major ions and isotopic results in drinking-water wells from this study to data available on the same formations (Catskill and Lockhaven) in previous studies (24, 25) and to underlying brines throughout the Appalachian Basin (18)

	Active		Nonactive		Previous studies (background)		
	Lockhaven formation $N = 8$	Catskill formation $N = 25$	Catskill formation $N = 22$	Genesee group $N = 12$	Lockhaven formation (25) $N = 45$	Catskill formation (24) $N = 79$	Appalachian brines (18, 23) $N = 21$
Alkalinity as HCO_3^-,							
mg L^{-1}	285 ± 36	157 ± 56	127 ± 53	158 ± 56	209 ± 77	133 ± 61	150 ± 171
mM	[4.7 ± 0.6]	[2.6 ± 0.9]	[2.1 ± 0.9]	[2.6 ± 0.9]	[3.4 ± 1.3]	[2.2 ± 1.0]	[2.5 ± 2.8]
Sodium, mg L^{-1}	87 ± 22	23 ± 30	17 ± 25	29 ± 23	100 ± 312	21 ± 37	33,000 ± 11,000
Chloride, mg L^{-1}	25 ± 17	11 ± 12	17 ± 40	9 ± 19	132 ± 550	13 ± 42	92,000 ± 32,000
Calcium, mg L^{-1}	22 ± 12	31 ± 13	27 ± 9	26 ± 5	49 ± 39	29 ± 11	16,000 ± 7,000
Boron, μg L^{-1}	412 ± 156	93 ± 167	42 ± 93	200 ± 130	NA	NA	3,700 ± 3,500
$\delta^{11}B$ ‰	27 ± 4	22 ± 6	23 ± 6	26 ± 6	NA	NA	39 ± 6
^{226}Ra, *p*Ci L^{-1}	0.24 ± 0.2	0.16 ± 0.15	0.17 ± 0.14	0.2 ± 0.15	0.56 ± 0.74	NA	6,600 ± 5,600
$\delta^{2}H$, ‰, VSMOW	−66 ± 5	−64 ± 3	−68 ± 6	−76 ± 5	NA	NA	−41 ± 6
$\delta^{18}O$, ‰, VSMOW	−10 ± 1	−10 ± 0.5	−11 ± 1	−12 ± 1	NA	NA	−5 ± 1

Some data for the active Genesee Group and nonactive Lockhaven Formation are not included because of insufficient sample sizes (NA). Values represent means ±1 standard deviation. NA, not available.

N values for $\delta^{11}B$ ‰ analysis are 8, 10, 3, 6, and 5 for active Lockhaven, active Catskill, nonactive Genesee, nonactive Catskill, and brine, respectively. *N* values for ^{226}Ra are 6, 7, 3, 10, 5, and 13 for active Lockhaven, active Catskill, nonactive Genesee, nonactive Catskill, background Lockhaven, and brine, respectively. $\delta^{11}B$ ‰ normalized to National Institute of Standards and Technology Standard Reference Material 951. $\delta^{2}H$ and $\delta^{18}O$ normalized to Vienna Standard Mean Ocean Water (VSMOW).

firms to voluntarily report a list of the constituents in the fracturing fluids based on the Emergency Planning and Community Right-to-Know Act. More research is also needed on the mechanism of methane contamination, the potential health consequences of methane, and establishment of baseline methane data in other locations. We believe that systematic and independent data on groundwater quality, including dissolved-gas concentrations and isotopic compositions, should be collected before drilling operations begin in a region, as is already done in some states. Ideally, these data should be made available for public analysis, recognizing the privacy concerns that accompany this issue. Such baseline data would improve environmental safety, scientific knowledge, and public confidence. Similarly, long-term monitoring of groundwater and surface methane emissions during and after extraction would clarify the extent of problems and help identify the mechanisms behind them. Greater stewardship, knowledge, and—possibly—regulation are needed to ensure the sustainable future of shale-gas extraction.

Methods

A total of 68 drinking-water samples were collected in Pennsylvania and New York from bedrock aquifers (Lockhaven, 8; Catskill, 47; and Genesee, 13) that overlie the Marcellus or Utica shale formations (Fig. S1). Wells were purged to remove stagnant water, then monitored for pH, electrical conductance, and temperature until stable values were recorded. Samples were collected "upstream" of any treatment systems, as close to the water well as possible, and preserved in accordance with procedures detailed in *SI Methods*. Dissolved-gas samples were analyzed at Isotech Laboratories and water chemical and isotope (O, H, B, C, Ra) compositions were measured at Duke University (see *SI Methods* for analytical details).

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