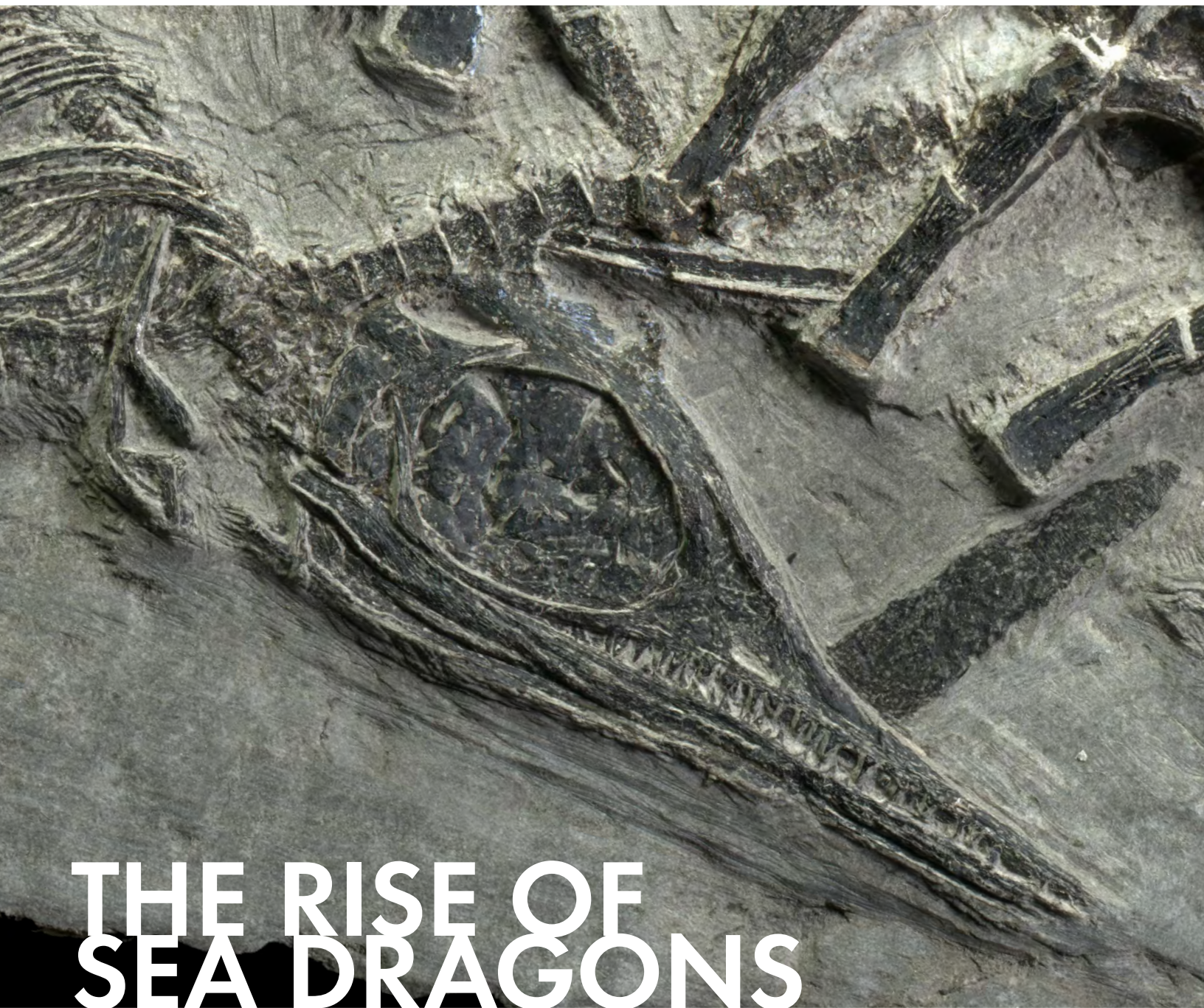




UC DAVIS

EARTH AND PLANETARY SCIENCES

**2014
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THE RISE OF SEA DRAGONS

in this issue:

Ryosuke Motani's Sea Dragons

The California Rock Garden: Our backyard classroom

Faculty News





UC Davis
 Earth and Planetary Sciences
 Newsletter, Volume 11

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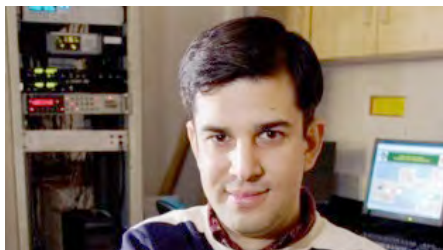
CHAIR'S WELCOME

Dear Friends, Alumni, and Colleagues,

The Department of Earth and Planetary Sciences is continuing to build on our strong research and teaching traditions. Three new faculty members have joined our department, enhancing our strengths in Planetary Sciences, Geophysics, Geochemistry, Environmental Sciences, Tectonics, and Sedimentology.



Professor Sarah Stewart brings expertise in the dynamic response of rocks and minerals to pressure, which she uses in numerical simulations of planetary collisions. We are constructing a light gas gun lab for her in a new building on campus, where she will recreate the pressure-temperature conditions of natural impact events and the interiors of planets. Sarah has strong ties to Lawrence Livermore National Laboratory where she uses high-energy lasers for similar experiments. Sarah's addition to our department significantly strengthens our expertise in planetary sciences, and her understanding of materials plus her modeling expertise add depth to our geophysics program.



Professor Sujoy Mukhopadhyay uses noble gas analyses to address diverse research questions, ranging from the origins of planetary atmospheres to the delivery of dust from the Sahara

to the Atlantic Ocean as a marker of desertification. The breadth of Sujoy's interests and the utility of noble gas analyses for tracing materials and determining ages ensure that he will enrich our department with diverse collaborations in planetary sciences, geochemistry, environmental sciences, tectonics and sedimentation. We have remodeled the machine shop on the first floor of the Earth and Physical Sciences building to accommodate Sujoy's mass spectrometers.



Professor Emerita Cathy Busby retired from UC Santa Barbara and moved to UC Davis, where she will continue her research on the interactions between tectonics and sedimentation. Her decades of research on the North American Cordilleran margin is continuing with active projects in Mexico, including a NSF funded Research Experiences for Undergraduates program in Baja California. Cathy's expertise nicely complements our strengths in tectonics and fills an important need for more expertise in siliciclastic sedimentation.



While welcoming these new faculty, two other faculty members are transitioning into a new phase: Professor Don Turcotte retired last fall and Professor Howard Day retired in June. Both intend to remain active in research as emeriti faculty, and we are very pleased to have them continuing their contributions to the dynamic research environment of the department.

Our graduate program is exceptionally strong, with outstanding opportunities



left to right: Jesslyn Starnes, M.S.; Amy Williams, Ph.D., Sinem Tanrikulu, M.S.



Congratulations to the Class of 2014

for our students in labs on campus, specialty labs elsewhere, and field areas around the world. We've sent students to every continent for fieldwork this year, including Antarctica. And we haven't neglected our local neighborhood: our students provided the first fault offset measurements in Napa Valley the day of the magnitude 6.0 earthquake in August.

Our undergraduate programs are also very active. Many of our majors are participating in research projects, exploring what it means to be Earth and planetary scientists outside of the classroom. The Geology Club and the student chapter of the American Institute of Professional Geologists are organizing field trips, hosting speakers, and helping their members prepare for careers after completing their undergraduate degrees. The new Coastal

and Marine Science major is growing, and the Natural Sciences major is serving an important cohort of students.

We are also helping train other STEM students and future teachers beyond our department. For example, the Mathematics and Science Teaching (MAST) program has been expanding over the past few years, and Professor Sandy Carlson is now Interim Director after Howard's retirement.

As you will read in the rest of the newsletter, the Department of Earth and Planetary Sciences is moving into an exciting new era marked by compelling research, expanding connections to society, and a continued focus on providing a high quality education for our students. It is truly a pleasure to represent this department as the new Chair. And I wish to thank each of you

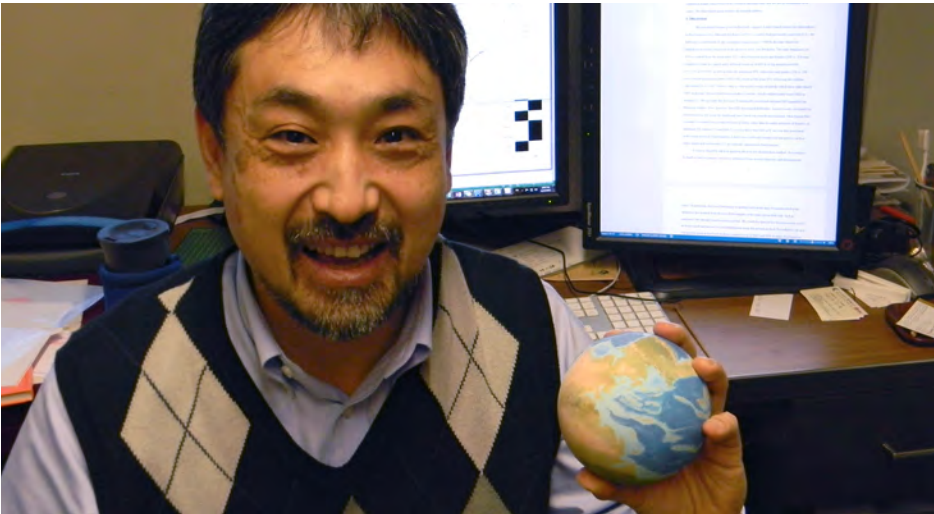
who have contributed to our successes by participating in our community and representing our department as you have moved on to the next phases in your careers. Please come by when you are in the neighborhood or send updates on your activities to geology@ucdavis.edu.

Cheers,

Dawn Sumner



Investigating the Rise of Sea Dragons after a Global Warming



Ryosuke Motani asks:

“Was there anything special about the environment of the time that encouraged them to invade the sea despite the many obstacles? Did climate change have anything to do with it?”

Featured Faculty **Ryosuke Motani**

Large marine reptiles, or sea dragons, inhabited the sea in the Mesozoic Era (about 252 to 65 million years ago) when dinosaurs roamed the land. These sea-going reptiles descended from land ancestors who somehow decided to invade the sea. Marine invasion is not easy: they had to learn to hold their breath extensively, drink salty water, and swim instead of walk – to list a few adaptations. Then, was there anything special about the environment of the time that encouraged them to invade the sea despite the many obstacles? Did climate change have anything to do with it? What evolutionary steps were actually taken by these reptiles during the transition from land to sea?



To answer these questions, we need to know when and where the marine invasions took place, under what environmental conditions, and which transitional species lived at the time. It is roughly known that the first wave of marine invasions by reptiles occurred during the Early Triassic after the end-Permian mass extinction, which was associated with a global warming. However, detailed information has been lacking.

I have been working with my international colleagues in a trial to answer these questions through

fieldwork in China. My collaboration with the Peking University in Beijing, China, has lasted for more than a decade; and my collaboration with the University of Milan, Italy, has entered its eighth year. Together, we have been examining the Lower Triassic strata in Anhui Province, China, to look

for the earliest evidence of marine reptiles. Two years ago, we started a new collaboration with the Wuhan Centre of China Geological Survey to expand the research area into Hubei Province, China, which is also known for Early Triassic marine reptiles.



The moment of birth in a *Chaohusaunus*, a primitive ichthyosaur species.





Cartorhynchus, a primitive 'cousin' of ichthyosaurs, fills a long-noted gap in the fossil record.

length. It had a thickened ribs that ballasted the animals in wavy waters, and unusually large flippers that allowed it to crawl clumsily on land. Most marine reptile and mammal lineages went through a transitional species that was heavily built and amphibious, so the new discovery fits the picture perfectly. The fossil is also about 248 million years old, suggesting that the ichthyosaur lineage evolved very fast around that time.



Over the last few years, we have been blessed with exciting new discoveries from Anhui, two of which made news around the world.



The first discovery was of a baby ichthyosaur. Ichthyosaurs are a group of marine reptiles that became fish-shaped after starting from a four-legged ancestor. Ichthyosaurs are often compared to dolphins; dolphins are also fish-shaped, despite their mammalian descent. That fossil, which is about 248 million years old, captured the moment of birth in a primitive ichthyosaur called *Chaohusaurus*. To our surprise, the species was giving birth to babies just like some land reptiles do today. That is, newborns came out headfirst in these primitive ichthyosaurs, while later ichthyosaurs, like dolphins, gave birth to babies tail-first. It seems that the land ancestor of ichthyosaurs were already giving live birth, as with about 10% of lizard species living today.



The second discovery was of a primitive 'cousin' of ichthyosaurs that filled a long-noted gap in the fossil record. Ichthyosaurs were first reported in 1814 based on a fossil collected by Mary Anning, who is perhaps best recognized as a putative model for the rhyme "She sells sea shells. ..." This was a few decades before the word 'dinosaur' was invented – imagine not knowing dinosaurs as a kid (!). Ichthyosaurs quickly became an iconic giant reptile from the past, triggering

a series of events that paved the way for the evolutionary theory of Charles Darwin. From early on, it was noticed that ichthyosaurs were reptiles despite their fishy appearance, yet nobody knew how this lineage transitioned from land to sea. Thus began a search for a transitional form, which ended up taking exactly two centuries.

It turned out that the transitional 'cousin' of ichthyosaurs, named *Cartorhynchus*, was a small animal, measuring less than 1.5 feet in total

I am hoping to clarify the marine invasions by Mesozoic reptiles further. With help from Isabel Montañez, we are now scrutinizing the environmental and chronological settings of these early marine invaders, and the relevance to the global warming of the time. This study also allows us to investigate how long it took the biosphere to recover from the end-Permian mass extinction, and if the recovery was gradual or punctuated.



Majiashan near Chaohu City, Anhui Province, China, where we discovered the fossils. We were initially competing for the limestone against mining industries collecting limestone to sell for construction. In this photo, you can see the shovel on the right just breaking the rock bed known as the "ichthyosaur-bed". It contains precious fossils that are found nowhere else in the world. My colleague Professor Andrea Tintori (University of Milan) is trying to find one more fossil before they destroy the whole area. A year later, our findings convinced the local politicians to stop the mining activity around this small hill; because when the hill is gone, so are the fossils that are unique to this area.

THE CALIFORNIA ROCK GARDEN at the Earth and Physical Sciences Building



by Peter Schiffman, Emeritus Professor

After over four years, the California Rock Garden around the Earth and Physical Sciences building is now complete, with informational signage, as well as a [downloadable pdf map](#) available on our department web site.



The California Rock Garden was created out of the vision of several UC Davis alumni, faculty, staff, and friends, who wanted to adorn the exterior of the newly constructed Earth and Physical Sciences building with both native California plants and rocks. The (then) Geology Department partnered with the UC Davis Arboretum to make this space part of the GATEways Project that is integrating the campus landscape into its academic culture.

Amassing, transporting, and installing the fifty plus boulders for the California Rock Garden turned out to be a major logistical undertaking. UC Davis Geology alumnus Jeff Light (M.S., 2001) was working as a geologist for Granite Construction in 2008 when I took over as department chair for the big move from the Physics/Geology building into our new digs. Granite Construction has rock quarries throughout the state and – through Jeff’s efforts – they set aside and eventually transported around thirty specimen boulders for the California Rock Garden. Homestake Mining and the McLaughlin Natural Reserve

donated another dozen or so boulders of hydrothermal sinter and volcanic breccia. Emgold Mining of Grass Valley donated another dozen large (5' diameter) cores of serpentinite and gabbro recovered from an 1125' vertical ventilation shaft bored into the Idaho Maryland Mine in the 1930's.

Donations from passionate individuals rounded out the California Rock Garden collection. Donn Ristau (Ph.D., 1977) and Skyler Phelps donated a boulder of *Turritella*-bearing sandstone from Cement Hill in Solano County. Jim Wood donated several large fragments of petrified “drift” wood from Tertiary gravels in the Sierra foothills. And perhaps the masterpiece of the California Rock Garden – a giant polished slab of greenstone from the

Smartville ophiolite – was prepared and donated by Ralph Mullican of Yuba Blue Boulders.



Now completed, the California Rock Garden has become integrated into “field” exercises for introductory classes like Physical Geology, as well as upper division Geology major courses in Structural Geology, Igneous and Metamorphic Petrology, and Field Methods. But it is also a destination location for scores of K-12 school groups from the greater Davis/Sacramento area. A quick stop off of I-80, it's a great place for all you departmental alums to get back to your roots and remind yourselves why you love Geology so much!



EARTH AND PLANETARY SCIENCES FACULTY NEWS

Magali Billen. In the past year, my research group has continued to focus on questions related to the dynamics of subduction zones – with virtual field trips to Tonga-Kermadec, Costa Rica, and South America. Ph.D. student Katrina Arredondo is narrowing in on the affect of phase transitions in the mantle on the motion of tectonic plates at the surface (it all depends on slab strength!). In a related project M.S. student John Bikoba is analyzing various observations related to the world's deepest earthquakes, which occur in sinking tectonic plates at depths of 400 to 660 km. I've also enjoyed continuing my collaborations with post-doc John Naliboff on numerical simulations of the formation of outer rise faults and with Juan Rodriguez-Gonzalez on the role of the overriding plate in affecting the dip of subducting slabs. Looking to the future, both Katrina and new Ph.D. student Scott Tarlow will be shifting their numerical modeling to a new code called ASPECT; we hope that by making this shift to a more powerful and flexible code, we will be able to increase the realism of the models and more quickly explore a larger range of parameters and geological scenarios. Outside of the world of subduction, I was on leave for part of the last year to spend time with my twin daughters, Eliane and Sophie (born May 23, 2013). Their big brother Lucas is enjoying playing and looking out for his little sisters.



Sandy Carlson's research focuses on brachiopod (bivalved marine invertebrates) evolutionary biology and paleobiology: how and why have brachiopods evolved in the ways that they have, and what evidence does the fossil record provide? She has been working on an NSF-funded project to test the assumption, widely held among paleontologists, that the shell morphology of living and fossil brachiopods is an accurate source of information on evolutionary (phylogenetic) relationships. By comparing patterns of morphological evolution with patterns of molecular evolution determined from the roughly 5% of brachiopod species living today, she and post-docs Holly Schreiber and Dave Bapst are determining which shell characters in extinct species are trustworthy guides to their evolution, and which appear to be related instead to their function and behavior. This year, they are working on a combined analysis of morphology and molecular sequence data of the Recent rhynchonellide brachiopods, and were invited to present their results at the Society for the Study of Evolution meetings in June 2014. They are also investigating similarities and differences between ontogenetic and phylogenetic transformations based on increases in body size over the lifespan of an individual and the evolution of a clade. Carlson presented one aspect of the results of this research at the Fourth International Palaeontological Congress in Mendoza, Argentina, where she had the opportunity to visit some Andean fossil field sites visited by Charles Darwin between 1833 and 1835. Carlson and Schreiber are working with department illustrator extraordinaire Janice Fong to develop a website of images generated from 3D microCT scans of brachiopods, that can be manipulated and analyzed in 3D. Natalia Lopez-Carranza, Carlson's Ph.D. student, has begun working on a project to characterize and compare genetic and



Standing beside one of dozens of upright fossil tree trunks, Triassic in age, west of Mendoza, known locally as "Darwin's trees".

morphological variability in species of extant brachiopods, and then use that comparison to evaluate variability in size and shape within and among extinct species and their close extant relatives. And Olga Beketova is completing a M.S. degree that investigates the extent to which a fluid percolation model can be used to model the dispersal of camels from their evolutionary center of origin in North America over 40 million years ago to their current geographic distribution today.

Carlson served as the President of the Paleontological Society since November 2012, and just completed the second year of a two-year term; she continues for two more years as Past-President with a new set of responsibilities. As President, she led the effort to establish a contractual partnership with Cambridge University Press to publish *Journal of Paleontology* and *Paleobiology*, ending 88 years of self-publishing activity that was becoming less economically attractive in light of the rapidly changing landscape of 21st century scientific publishing.





Kari sampling rhyolitic pumice at the Taupo Volcanic Zone, New Zealand

Kari Cooper. 2014 was an eventful year for my research group. Ph.D. student Allie Rubin and I went to New Zealand in late January to do field work, followed immediately by a conference in Australia in early February. That happened to coincide with the publication of a paper in *Nature* where my coauthor and I presented results showing that magmas at Mount Hood – and likely many arc volcanoes – spent the majority of their history in “cold storage” as a crystal mush, with only short-lived bouts as an eruptible magma. This led to some scheduling challenges related to the press activity that accompanied publication, working around a quirky hotel phone system, the time change, and the conference schedule! We are starting a new project to examine a number of other volcanic systems to test whether this conclusion holds elsewhere, and what are the variables that control the thermal conditions of magma storage. Ph.D. student Kevin Shrecengost has been starting this off, looking at Lassen Volcanic Center, Pinatubo, and Volcan Quizapu, Chile. M.S. student David Houchins has also continued to work on developing carbonate dating, and plans to finish his degree in spring of 2015. More

changes in the lab group are coming up soon, with Ph.D. student Mark Stelten defended his dissertation, on magmatic processes at Yellowstone, in December. We will miss his contributions to the group, but fortunately he won't be far away – he has a postdoc position at the USGS in Menlo Park which will start two weeks after his defense.



Eric Cowgill. My research uses geologic observations to quantify the deformational response of the continental crust to plate collision. In the last year I've worked in three main directions. My main focus has been on the Cenozoic evolution of the Greater Caucasus Mountains in the Arabia-Eurasia collision zone with Adam Forte (Ph.D., 2012, now a prize-postdoc at ASU), current Ph.D. student Chad Trexler, and collaborators at Michigan and Ilia State University in Tbilisi, Republic of Georgia. We've used U-Pb detrital zircon data to investigate formation of the range by subduction of a relict-basin analogous to the South Caspian, earthquake data to obtain the first clear image of a subducted slab beneath the range, and geologic mapping and balanced sections to determine total upper-crustal shortening for comparison with the magnitude of post-collisional subduction. We're also investigating possible surface-rupturing earthquakes on thrust faults along the southern flank of the range. A second major focus is on determining the magnitude of Cenozoic shortening across the NW margin of the Tibetan Plateau in the Indo-Eurasia collision zone with Ph.D. student John McDermott, colleague Mike Oskin, and

Eric Cowgill



October 2014 fieldwork in China with Mike Oskin and students John McDermott and Veronica Prush.

collaborators at Zhejiang University and the China Earthquake Administration. A third main focus has been on investigating temporal variations in rates of fault slip along both the Mojave section of the San Andreas fault in southern California and the Altyn Tagh fault in NW China with M.S. student Mary Barr and USGS collaborators, including Ryan Gold (Ph.D., 2009) who is now a Research Geologist with USGS.



Tessa Hill. It has been a busy year in the Hill lab! This year we embarked on several new research avenues, both near and far. I completed fieldwork in California, Oregon, and Washington in spring and fall (for the 5th year in a row), to assess the impact of ocean acidification on nearshore environments. We began an investigations tidepools of Bodega Head, to understand the geochemical conditions under which invertebrates precipitate shell material. My colleagues and I also initiated a new CA Sea Grant project to understand the role of seagrass beds in altering coastal geochemistry. My students and postdocs continue to be very productive, working on projects that include paleoecology, culturing of living foraminifera, and investigating the geochemistry of the California mussel. With the UC Davis Mathematics and Science Teaching (MAST) program, we are working to convert results of these studies into 6th grade curriculum. Members of my lab also had the fortune of joining Dr. Ken Caldeira in Australia, to investigate calcification processes along the Great Barrier Reef. It has been a year of “partnerships” – our ongoing work has been made possible by collaborations with individuals at the Carnegie Institution, California Academy of Sciences, National Marine Sanctuaries, Point Blue Conservation Science, Marine Conservation Institute and Hog Island Oyster Company.



Louise Kellogg. The last year was very lively as I took on a stint as acting chair. Together with my previous term as department chair, last year

rounds out more than a decade of “chairfulness”. I continue as director of the Computational Infrastructure for Geodynamics, and of the KeckCAVES visualization lab. My group continues to use computer models to understand convection in the Earth’s mantle and interaction of faults. The KeckCAVES team, including Earth and Planetary Sciences researchers Burak Yikilmaz and Oliver Kreylos, has been bringing 3D visualization technologies to museum settings to explain the geologic processes at work in lakes and their watersheds. Working with science centers Tahoe Environmental Research Center, the Lawrence Hall of Science, and the Echo Lake Center in Vermont, we developed Great Lakes of the World, a series of datasets and visualizations combining satellite imagery, high resolution topography, and bathymetry to tell the geologic story of each lake. Our team also developed an Augmented Reality Sandbox, allowing children (and grownups) to explore the formation of watersheds. In partnership with the Exploratorium we have built several of these for museums around the country.



Isabel (second from left) and her colleagues in China, including her son Dillon Osleger (far right).

Isabel Montañez. It’s been an exciting time in our research group with six graduate students, two postdoctoral scholars, a couple of undergraduates and several international (Spain, Ireland, China) visitors this past year. Our efforts continue to be focused on paleoclimates of the past including the last icehouse and the most recent deglaciation.

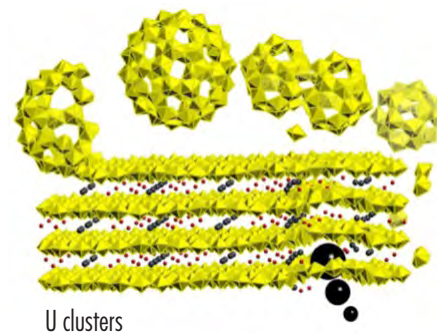
Graduate students Galen Griggs and Jon Richey are unraveling vegetation-climate feedbacks of the Carboniferous through a data-model integration funded by NSF’s new program Earth-Life Transitions. Julie Griffin and Rawan Alasad are focused on glacioeustasy and orbital climate forcing in marine and Carboniferous terrestrial systems in North America and Europe, while Neil Griffis is reconstructing southern Gondwanan ice sheet behavior in the Parana Basin, Brazil – with support from NSF’s CNIC program. Postdoctoral fellow, Corinne Wong (soon to be an asst. professor at Boston College), and Ph.D. student Matthew Renquist are working on reconstructing regional climate response in the American Southwest to warming of the last deglaciation through speleothem proxy records and regional climate modeling. Their efforts are part of an NSF-funded (EAGER) collaboration with Kari Cooper and Research Associate Jerry Potter. Jitao Chen joined us recently as a postdoctoral scholar and is working on unraveling the links between C cycling, glacioeustasy, and climate across major boundary events in the Permo-Carboniferous of south China. And Isabel, she’s busy herding these cats and making sure they are intellectually and financially well fed.



Alex Navrotsky. Our Energy Frontier Research Center, Materials Science of Actinides, has been renewed for four years by the Department of Energy. It is led by Peter Burns (a mineralogist) at Notre Dame and UC Davis participants are Alex Navrotsky and Bill Casey. We have been working on the thermodynamic, structure, and reactivity of solids and aqueous clusters containing uranium, thorium, neptunium and, now that Los Alamos National Lab is a partner in the renewal, plutonium.

Navrotsky’s group is also a partner in the DOE “Hub”, the Critical Materials Institute, which studies elements critical to technology and potentially in short supply, especially

the rare earths (lanthanides). The UC Davis contribution is fundamental thermodynamics of rare earth minerals.



Mike Oskin. I am pleased to report new Ph.D. students and new research directions for 2013-2014. Alex Morelan joined my group in 2013. He is working with me on several problems in active tectonics in the western U.S., including the relationship of rapid rock uplift in the San Geronio pass to slip on the San Andreas fault, and deciphering the interplay of strike-slip faulting with the morphology of alluvial fan deposits. For the latter project, Alex acquired a quadcopter drone with Durrell funding support. With this instrument he is experimenting with the production of 3D topographic models from photogrammetry. Two new students joined my group in 2014. Veronica Prush is working on the slip in great earthquakes on the Altyn Tagh fault in western China, picking up the next phase of this project from Austin Elliott (Austin defended his Ph.D. in November). Another new student, Yiran Wang, is exploring Ph.D. project ideas in the Qilian Shan region of central China. Alex, Veronica, and Yiran have also become involved in a rapid-scientific-response research project focussed on the August 24 Napa earthquake. Alex, together with Chad Trexler (Ph.D. student from Eric Cowgill’s group) mapped the extent of the surface rupture on the day of the event, becoming somewhat internet-famous in the process, thanks to some promotion on Twitter. As part of a follow-up graduate course we mapped previously unreported active strands of the West Napa fault in the northern part of Napa valley, and we are now

beginning to assess a post-earthquake lidar data set collected from over the surface rupture.



Surface rupture from the 2014 South Napa earthquake. Fractures formed as en-echelon R-shears (can you discern the slip sense?). Linking of these fractures generated a classic 'mole-track'.



Howie Spero. The past year has been a whirlwind in the Stable Isotope Laboratory. Lael 'Spider' Vetter (Ph.D., 2013) finished an innovative dissertation that explored the carbon and oxygen isotope geochemistry of foraminifera shells at the micron scale with SIMS, and developed a novel technique to reconstruct continental ice sheet melt geochemistry using laser ablation ICPMS with IRMS geochemistry. Brittany Grimm (M.S., 2013) completed her research on the geochemistry (^{14}C , ^{13}C and ^{18}O) of oysters collected from early 17th century archaeological sites in Virginia that included the original Jamestown settlement and Anthony Menicucci is completing experiments on the oxygen isotope composition of biogenic opal in marine and lacustrine systems using a microfluorination technique that he developed last year. Postdoc Jennifer Fehrenbacher has been conducting experiments on living foraminifera and refining our laser ablation ICPMS system for novel applications.

This past year, I spent 6 months in Germany at the Alfred Wegener Institute as part of a Humboldt Research Award. I am now working on the geochemistry and mechanisms controlling calcification

and biomineralization in planktonic foraminifera together with a new postdoc, Dr. Oscar Branson, from Cambridge England. We have been conducting experiments with living foraminifera and exploring the geochemistry of calcification with ultrahigh resolution using NanoSIMS, Atom Probe Tomography and Cryo-TOF SIMS.



Sarah Stewart's research program focuses on planet formation and evolution with an emphasis on collisional processes. She is a specialist in experimental shock physics studies of natural materials and numerical studies of planetary collisions. Shockwave data are essential for a wide range of problems in Earth and Planetary Sciences, including planetary accretion and disruption, impact crater formation, the high-pressure states in planetary interiors, and interpreting astronomical observations of collisions in exoplanetary systems. Shockwave experiments yield fundamental data on the equations of state and constitutive relations of planetary materials as well as reproducing the wide range of pressure-temperature space sampled during planet formation and evolution.



Rendering of the 3000-ft² Shock Compression Laboratory building at UC Davis, a new world-class shock physics facility for research and education. The laboratory experimental capabilities will include a 40-mm single stage gas/powder gun and 25-mm two-stage light gas gun, capable of launching projectiles to 8 km/s and generating the high pressure states found in the Earth's mantle and core. The Shock Compression Laboratory focuses on planetary science applications of High Energy Density physics, such as the Moon-forming giant impact. (right, Fig. from Čuk and Stewart, 2012).

Čuk, M., and S. T. Stewart (2012), Making the Moon from a Fast-Spinning Earth: A Giant Impact Followed by Resonant Despinning, *Science*, 338, 1047-1052, doi:10.1126/science.1225542.



Geerat Vermeij. I have been writing lots of papers and taking interesting trips, several of which were connected with field work. In particular, a field excursion to Patagonia following the Fourth International Paleontological Congress in Mendoza, Argentina, acquainted me with the vast oyster reefs of the Puerto Madryn Formation (supposedly Late Miocene), one of the great wonders of the world's sedimentary record. I have also worked at Naturalis, the Dutch natural-history museum, on various projects including the description of some fossil Indonesian modiolid gastropods.



Robert Zierenberg's research continues to be focused on water/rock interactions in geothermal systems. Ph.D. student Andrew Fowler is investigating the partitioning of Rare Earth Elements between fluids and hydrothermal alteration minerals in a variety of geothermal systems. Master's student Caroline Cantwell is finishing her study of an acid-sulfate geothermal system in the Philippines. Z returned to Iceland in Fall to participate in two International Continental Scientific Drilling Program Workshops that will lead to proposals for future geothermal drilling projects. One proposal seeks to obtain drill core across the thermal boundary layer and into the rhyolitic magma body that the Iceland Deep Drilling Project intercepted while attempting to drill a deep high temperature well at the Krafla Geothermal Field. This was the world's highest temperature producing geothermal well, venting superheated steam at 450° C before the well needed to be shut down for casing and valve repair. A second project seeks to core through the Surtsey volcano to investigate the volcanological, geochemical, and microbiological evolution of this island that formed from an eruption off the south coast of Iceland in 1969. Planning is also continuing for drilling a deep well at the Reykjanes Geothermal field in Iceland where we hope to intersect and produce super critical hydrothermal fluids from the deep reaction zone of a geothermal system that displays the chemical characteristics of a "black smoker" system such as those that deposit Cu-Zn-Ag-Au massive sulfide deposits on the mid-ocean ridges.

RESEARCH SCIENTISTS

Cathy Busby has joined the department as Professor Emerita on Return To Active Duty. She holds a B.S. from UC Berkeley (1977), a Ph.D. from Princeton University (1983), and was on the faculty at UC Santa Barbara for 32 years. Cathy is a field-based geologist, doing research in sedimentology, volcanology, and structural geology

in convergent margin and rift tectonic settings. Her work is mainly sponsored by the National Science Foundation, but has also been supported by the geothermal, mineral and petroleum industries, and the U.S. Geological Survey. Most recently, Cathy has become involved in oceanographic research, serving as Co-Chief Scientist on International Ocean Discovery Program Expedition 350 to the Izu-Bonin arc (2014). Cathy currently holds three NSF awards, including the Baja Basins Research Experience for Undergraduates site. She is an AAPG Distinguished Lecturer (2014-2015), and she teaches short courses and field workshops on sedimentary tectonics, deepwater sedimentation, and volcanic-volcaniclastic geology.



Ann Russell. Much of our understanding of changes in ocean temperature over tens to millions of years is based on the shell geochemistry of surface-ocean planktic foraminifera ("forams"). Over the last year, I continued my NSF-funded research to expand the application of geochemical

proxies into deeper waters by quantifying relationships between shell geochemistry and temperature in species of planktic forams that live below the mixed layer. With my co-PI Dr. Jennifer Fehrenbacher, I led a diverse group of undergraduate and graduate students, as well as postdocs from several institutions, to conduct controlled experiments with living forams at the Bodega Marine Laboratory and at the Wrigley Marine Science Center. We use a sophisticated metal isotope spike technique, combined with laser ablation mass spectrometry and nanoSIMS analysis, to identify the portion of the shell grown under specific culture conditions and to explore the fundamental mechanisms by which trace metals are incorporated into shell calcite. Our research will expand the range of oceanic depths that can be probed with geochemical proxies, improving our ability to investigate environmental changes in the ancient ocean below the surface mixed layer, where most previous research has focused, and increase the level of confidence with which these geochemical proxies are applied.



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Students working hard at night
on a map analysis exercise at Little Poleta.