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MEETING ANNOUNCEMENT

DATE: October 26, 2016

LOCATION: Orinda Masonic Center, 9 Altarinda Rd., Orinda

TIME: 6:30 p.m. social; 7:00 pm talk (no dinner) Cost: $5 per regular member; $1 per student or K – 12 teachers

SPEAKER: **Brian D. Collins, Ph.D., P.E., Research Civil Engineer, U.S. Geological Survey**

Topic: Processes of exfoliation-induced rock falls: Recent studies from California's Sierra Nevada

Granitic rocks in the Sierra Nevada are known for their dramatic displays of exfoliation – the "peeling off" of the outer layer of rock that often manifests itself in massive arches and domes such as found in Yosemite and Kings Canyon National Parks, among many other high and low peaks in the Sierra Nevada mountains. When exposed in vertical exposures, these exfoliation "sheets" (as they are often called) can fracture and break off, causing potentially hazardous rock falls. But what causes fracture and over what time scales might exfoliation-related fracture occur? This presentation will share recent research on the process of exfoliation, and specifically on what types of triggering mechanisms might be responsible for rock falls that occur on hot sunny days when other, more typical, triggers such as precipitation and freeze/thaw action are absent. In this context, an explanation for recent exfoliation events occurring in the Sierra Nevada mountains of California will be described.

Biography: Brian Collins is a research civil engineer with the USGS Landslide Hazards Program in Menlo Park, California. He has worked in the landslide hazard field for the past 20 years including 10 years with the USGS. Dr. Collins currently leads projects on a variety of landslide topics, ranging from predicting shallow landslides and debris flows in the San Francisco Bay area, to understanding the mobility of the deep-seated 2014 Oso, Washington debris flow avalanche, to studying rock fall hazards in Yosemite National Park. He has degrees from Purdue University (B.S.C.E.), the University of Colorado, Boulder (M.S. – geotechnical engineering), and the University of California, Berkeley (Ph.D. – geotechnical engineering), and is a registered professional engineer in California.

NCGS 2016 – 2017 Calendar

November 16, 2016 (one week early) 7:00 pm
Dr. Julia Sigwart, Associate Professor and UCMP Visiting Scholar

Two Miles Underwater: A Voyage to the Bottom of the Sea

NCGS Field Trips

Field trips in a preliminary planning stage:

- Geology of Devil's Slide
- Pt. Sal Ophiolite in Santa Barbara Co,
- Convergent Margin Tectonics across Central California Coast Ranges - Pacheco Pass
- Tuscan Formation volcanic mudflow deposits, Cascade foothills

Peninsula Geologic Society

For an updated list of meetings, abstracts, and field trips go to http://www.diggles.com/pgs/. The PGS has also posted guidebooks for downloading, as well as photographs from recent field trips at this web address. Please check the website for current details.

UC Berkeley Earth & Planetary Science Weekly Seminar Series

Interesting seminars are presented weekly at EPS throughout the academic year, generally from late August through early May. Seminars are held Thursdays at 4 pm at 141 McCone. Fall speakers are listed and include Peter Molnar, but titles are not currently available beyond October 13.

For an updated list of seminars, go to http://eps.berkeley.edu/events/seminars.

Welcome back, everyone! Now: *It's Renewal Time!* Our Year Runs From September to September. If you haven't already renewed, please use the Renewal Form in previous newsletter, or see the Treasurer at the meeting at registration time.

Important NCGS note:

We are searching for a new secretary!

Our current secretary, Dan Day, has served superbly for many years, and needs a break. Something about moving out of state – to Oregon! We wish him well and thank him for his many years of service to NCGS in several different roles. If you are interested in taking on the secretary position, or know someone who is, please contact a member of the Nominating Committee (Ray Sullivan, Tom Barry, and Mark Sorensen) or the President by email or at the next meeting.

NCGS members are invited to attend any of our **NCGS Board meetings** held quarterly throughout the year (except for summer), generally in September, January, and May, at the CB&I (formerly Shaw E&I) offices at 4005 Port Chicago Hwy, Concord, CA 94520. The next board meeting has not yet been scheduled, but will likely be in early- to mid-January 2017.

Update on Millenium Tower

We have a technical update on the tilting Millenium Tower, at 58 stories the largest residential building in downtown SF. As mentioned in last month's newsletter, NCGS member Ray Sullivan (Prof. Emeritus, San Francisco State University) was interviewed about the issue by CBS News in August. This link provides a brief geotechnical summary and a stratigraphic column:

http://www.geoprac.net/geonews-mainmenu-63/41-miscellaneous/1729-san-francisco-millennium-tower-has-settled-16-inches#comment-716

How wetlands and agriculture, not fossil fuels, could be causing a global rise in methane

Wetlands and agriculture, not fossil fuels could be causing a global rise in methane, suggest investigators.

Credit: © Željko Radojko / Fotolia

Research published in the American Geophysical Union's journal *Global Biogeochemical Cycles* shows that recent rises in levels of methane in our atmosphere is being driven by biological sources, such as swamp gas, cow burps, or rice fields, rather than fossil fuel emissions.

Atmospheric methane is a major greenhouse gas that traps heat in our atmosphere, contributing to global warming. Its levels have been growing strongly since 2007, and in 2014 the growth rate of methane in the atmosphere was double that of previous years, largely driven by biological sources as opposed to fossil fuel emissions.

Conventional wisdom refuted

The study, led by researchers at Royal Holloway, University of London shows that methane emissions have been increasing, particularly in the tropics. Researchers discovered that biological sources, such as methane emissions from swamps, make up the majority of increase.

"Our results go against conventional thinking that the recent increase in atmospheric methane must be caused by increased emissions from natural gas, oil, and coal production. Our analysis of methane's isotopic composition clearly points to increased emissions from microbial sources, such as wetlands or agriculture" said lead author Euan Nisbet from Royal Holloway, University of London's Department of Earth Sciences.

Methane growth rate doubles

Professor Nisbet says "Atmospheric methane is one of the most potent greenhouses gases. Methane increased through most of the 20th century, driven largely by leaks from the gas and coal industries."

He continued, "At the beginning of this century it appeared that the amount of methane in the air was stabilising, but since 2007 the levels of methane have started growing again. The year 2014 was extreme, with the growth rate doubling, and large increases seen across the globe."

Tropics identified as key source

The research shows that in recent years, the increase in methane has been driven by sharp increases in the tropics, in response to changing weather patterns. It is possible that the natural processes that remove methane from the atmosphere have slowed down, but it is more likely that there's been an increase of methane emission instead, especially from the hot wet tropics.

Professor Nisbet and his team, together with the US The National Oceanic and Atmospheric Administration (NOAA), have been looking at measurements and samples of air taken from places like Alert in the Canadian Arctic; Ascension, a UK territory in the South Atlantic; Cape Point, South Africa.

International collaboration leads to new conclusions

The research has been carried out by an international team of atmospheric scientists, led by Euan Nisbet, from Royal Holloway, University of London. Ed Dlugokencky, from the NOAA, Martin Manning from Victoria University, Wellington, New Zealand and a team from the University of Colorado's Institute of Arctic and Alpine Research, led by Jim White, have been working with collaborators from the UK, France, Canada, and South Africa.

Story Source: Materials provided by University of Royal Holloway London.

Journal Reference: E. G. Nisbet, E. J. Dlugokencky, M. R. Manning, D. Lowry, R. E. Fisher, J. L. France, S. E. Michel, J. B. Miller, J. W. C. White, B. Vaughn, P. Bousquet, J. A. Pyle, N. J. Warwick, M. Cain, R. Brownlow, G. Zazzeri, M. Lanoisellé, A. C. Manning, E. Gloor, D. E. J. Worthy, E.-G. Brunke, C. Labuschagne, E. W. Wolff, A. L. Ganesan. Rising atmospheric methane: 2007-14 growth and isotopic shift.. *Global Biogeochemical Cycles*, 2016; DOI: 10.1002/2016GB005406.

Ancient rocks reveal how Earth recovered from mass extinction

Analysis of rocks unearthed in Oman that were formed in an ancient ocean around the time of Earth's greatest mass extinction have helped explain why life on Earth took so long to recover. *Credit: D. Astratti*

Scientists have shed light on why life on Earth took millions of years to recover from the greatest mass extinction of all time.

The study provides fresh insight into how Earth's oceans became starved of oxygen in the wake of the event 252 million years ago, delaying the recovery of life by five million years.

Findings from the study are helping scientists to better understand how environmental change can have disastrous consequences for life on Earth.

The Permian-Triassic Boundary extinction wiped out more than 90 per cent of marine life and around two thirds of animals living on land. During the recovery period, Earth's oceans became starved of oxygen -- conditions known as anoxia.

Previous research suggested the mass extinction and delayed recovery were linked to the presence of anoxic waters that also contained high levels of harmful compounds known as sulfides.

However, researchers say anoxic conditions at the time were more complex, and that this toxic, sulfide-rich state was not present throughout all the world's oceans. The team, led by researchers at the University of Edinburgh, used precise chemical techniques to analyze rocks unearthed in Oman that were formed in an ancient ocean around the time of the extinction.

Data from six sampling sites, spanning shallow regions to the deeper ocean, reveal that while the water was lacking in oxygen, toxic sulfide was not present. Instead, the waters were rich in iron. The finding suggests that iron-rich, low oxygen waters were a major cause of the delayed recovery of marine life following the mass extinction.

The study also shows how oxygen levels varied at different depths in the ocean. While low oxygen levels were present at some depths and restricted the recovery of marine life, shallower waters contained oxygen for short periods, briefly supporting diverse forms of life.

The precise cause of the long recovery period remains unclear, but increased run-off from erosion of rocks on land -- caused by high global temperatures -- likely triggered anoxic conditions in the oceans, researchers say.

The study, published in the journal *Nature Communications*, was funded by the Natural Environment Research Council and the International Centre for Carbonate Reservoirs. The work is a contribution to the UNESCO International Geoscience Programme. It was carried out in collaboration with the Universities of Leeds, Gratz, Bremen and Vienna University.

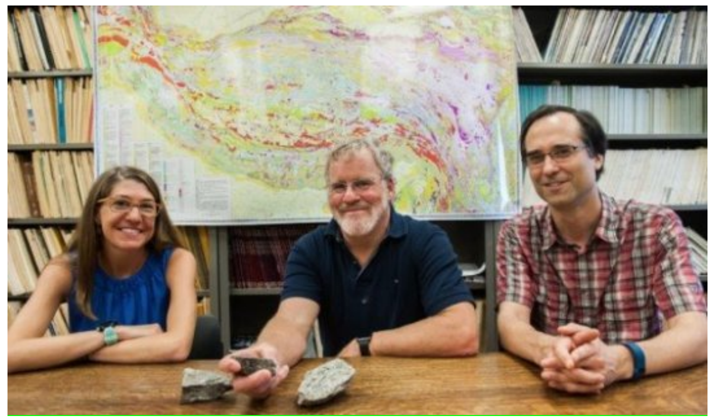
Dr Matthew Clarkson, of the University of Edinburgh's School of GeoSciences, who led the study, said: "We knew that lack of oxygen in the oceans played a key role in the extinction and recovery processes, but we are still discovering how exactly it was involved. Our findings about the chemistry of the ocean at the time provide us with a clearer picture of how this complex process delayed the recovery of life for so long."

Professor Simon Poulton, of the University of Leeds, who co-authored the study, said: "The neat point about this study is that it shows just how critical an absence of oxygen, rather than the presence of toxic sulphide, was to the survival of animal life. We found that marine organisms were able to rapidly recolonize areas where oxygen became available."

Story Source: Materials provided by University of Edinburgh.

Journal Reference: M. O. Clarkson, R. A. Wood, S. W. Poulton, S. Richoz, R. J. Newton, S. A. Kasemann, F. Bowyer, L. Krystyn. Dynamic anoxic ferruginous conditions during the end-Permian mass extinction and recovery. *Nature Communications*, 2016; 7: 12236 DOI: 10.1038/ncomms12236.

Case of Earth's missing continental crust solved: It sank



University of Chicago scientists and a colleague at Miami University of Ohio have concluded that half the original mass of Eurasia and India disappeared into the Earth's interior before the two continents began their slow-motion collision approximately 60 million years ago. The participating UChicago scientists are (from left) Miquela Ingalls, doctoral student in geophysical sciences; David Rowley, professor in geophysical sciences; and Albert Colman, assistant professor in geophysical sciences. Rowley holds a rock of the type they believe sank into the interior.

Credit: Jean Lachat

How do you make half the mass of two continents disappear? To answer that question, you first need to discover that it's missing. That's what a trio of University of Chicago geoscientists and their collaborator did, and their explanation for where the mass went significantly changes prevailing ideas about what can happen when continents collide. It also has important implications for our understanding of when the continents grew to their present size and how the chemistry of Earth's interior has evolved.

The study, published online Sept. 19 in Nature Geoscience, examines the collision of Eurasia and India, which began about 60 million years ago, created the Himalayas and is still in (slow) progress. The scientists computed with unprecedented precision the amount of landmass, or "continental crust," before and after the collision.

"What we found is that half of the mass that was there 60 million years ago is missing from Earth's surface today," said Miquela Ingalls, a graduate student in geophysical sciences who led the project as part of her doctoral work.

The result was unexpectedly large. After considering all other ways the mass might be accounted for, the researchers concluded that so huge a mass discrepancy could only be explained if the missing chunk had gone back down into Earth's mantle -- something geoscientists had considered more or less impossible on such a scale.

When tectonic plates come together, something has to give. According to plate tectonic theory, the surface of Earth comprises a mosaic of about a dozen rigid plates in relative motion. These plates move atop the upper mantle, and plates topped with thicker, more buoyant continental crust ride higher than those topped with thinner oceanic crust. Oceanic crust can dip and slide into the mantle, where it eventually mixes together with the mantle material. But continental crust like that involved in the Eurasia-India collision is less dense, and geologists have long believed that when it meets the mantle, it is pushed back up like a beach ball in water, never mixing back in.

Geology 101 miscreant

"We're taught in Geology 101 that continental crust is buoyant and can't descend into the mantle," Ingalls said. The new results throw that idea out the window.

"We really have significant amounts of crust that have disappeared from the crustal reservoir, and the only place that it can go is into the mantle," said David Rowley, a professor in geophysical sciences who is one of Ingalls' advisors and a collaborator on the project. "It used to be thought that the mantle and the crust interacted only in a relatively minor way. This work suggests that, at least in certain circumstances, that's not true."

The scientists' conclusion arose out of meticulous calculations of the amount of mass there before and after the collision, and a careful accounting of all possible ways it could have been distributed. Computing the amount of crust "before" is a contentious problem involving careful dating of the ages of strata and reconstructions of past plate positions, Ingalls said. Previous workers have done similar calculations but have often tried to force the "before" and "after" numbers to balance, "trying to make the system match up with what we think we already know about how tectonics works."

Ingalls and collaborators made no such assumptions. They used recently revised estimates about plate movements to figure out how large the two plates were at the onset of collision, and synthesized more than 20 years' worth of data on the geology of various regions of Earth to calculate how thick the crust would have been.

"By looking at all of the relevant data sets, we've been able to say what the mass of the crust was at the beginning of collision," Rowley said.

Limited options

There were only a few places for the displaced crust to go after the collision: Some was thrust upward, forming the Himalayas, some was eroded and deposited as enormous sedimentary deposits in the oceans, and some was squeezed out the sides of the colliding plates, forming Southeast Asia.

"But accounting for all of these different types of mass loss, we still find that half of the continental crust involved in this collision is missing today," Ingalls said. "If we've accounted for all possible solutions at the surface, it means the remaining mass must have been recycled wholesale into the mantle."

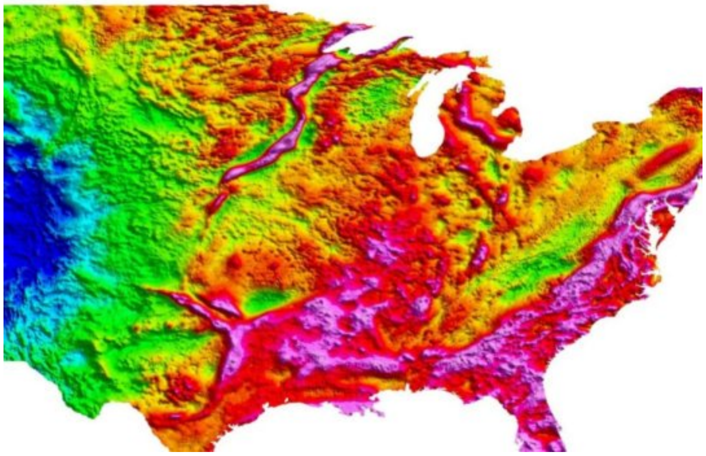
If large areas of continental crust are recycled back into the mantle, scientists can at last explain some previously puzzling geochemistry. Elements including lead and uranium are periodically erupted from the mantle through volcanic activity. Such elements are relatively abundant in continental crust, but scarce in the mantle. Yet the composition of some mantle-derived rocks indicates that they have been contaminated by continental crust. So how did continental material mix back into the mantle?

"The implication of our work is that, if we're seeing the India-Asia collision system as an ongoing process over Earth's history, there has been a continuous mixing of the continental crustal elements back into the mantle," said Rowley. "And they can then be re-extracted and seen in some of those volcanic materials that come out of the mantle today."

Story Source: Materials provided by University of Chicago.

Journal Reference: Miquela Ingalls, David B. Rowley, Brian Currie, Albert S. Colman. **Large-scale subduction of continental crust implied by India–Asia mass-balance calculation**. Nature Geoscience, 2016; DOI: 10.1038/ngeo2806.

Dense arrays of seismometers are letting scientists get a clearer look at a giant scar that underlies the American Midwest



Most of the gravity highs on this map (hot colors for high; cool ones for low) correspond with mountains or other topographical features. But the long snake-like gravity high heading south from the tip of Lake Superior is another story. There's nothing on the surface to explain its buried presence.

Credit: Image courtesy of USGS

When Doug Wiens approached Minnesota farmers to ask permission to install a seismometer on their land, he often got a puzzled look. "You could tell they were thinking 'Why are you putting a seismometer here?,' " said Wiens, professor of earth and planetary sciences in Arts & Sciences at Washington University in St. Louis. "'We don't have earthquakes and we don't have volcanoes. Do you know something we don't?' "

Actually, he did. Deep beneath the fertile flat farmland, there is a huge scar in the Earth called the Midcontinent Rift. This ancient and hidden feature bears silent witness to a time when the core of what would become North America nearly ripped apart. If the U-shaped rip had gone to completion, the land between its arms -- including at least half of what is now called the Midwest -- would have pulled away from North America, leaving a great ocean behind.

Weisen Shen, a postdoctoral research associate with Wiens, will be presenting seismic images of the rift at the annual meeting of the Geological Society of America (GSA) Sept. 25-28. The images were made by analyzing data from Earthscope, a National Science Foundation (NSF) program that deployed thousands of seismic instruments across America in the past 10 years.

What is that thing?

The Midcontinent Rift was discovered by geophysicists who noticed that gravity was stronger in some parts of the upper Midwest than in others. In the 1950s and 1960s, they mapped the gravity and magnetic anomalies with airborne sensors. Shen is contributing to a session at the GSA dedicated to Bill Heinze, a geophysicist who helped discover and map the Midcontinent Rift.

But understanding of the rift then stalled until 2003, when the NSF funded Earthscope, a program whose mission is to use North America as a natural laboratory to gain insight into how the Earth operates.

As part of Earthscope, the Incorporated Research Institutions for Seismology (IRIS) installed a network of 400 seismometers, called the USArray, that rolled across the United States from west to east, gathering data at each location for two years before moving on. USArray was installed on the West Coast beginning in 2004, and had advanced to the Midwest by 2010.

Earthscope also made available a pool of seismometers, called the flexible array, for more focused field experiments. A consortium of universities, including Washington University in St. Louis, installed 83 of these stations along and across the rift in 2011, creating a dense array called SPREE.

A telescope looking down

Seismologists had never before been able to blanket the landscape with seismometers in this way, and so the USArray has stimulated many innovations in the manipulation of the seismic data to extract information about Earth's crust and upper mantle.

Seismic interpretation is a thorny version of what is called an inverse problem. If the Earth's interior were of uniform composition, seismic waves would travel in straight lines. But instead, underground structures or differences in temperature and density refract and reflect them. The problem is to figure out mathematically which obstructions could have produced the wave arrivals that the seismometers recorded.

It's a bit like trying to figure out the shape of an island in a pond by throwing a pebble into the lake and recording the ripples arriving at the shore.

The data wizard on the Washington University team is Shen, who has devised new techniques for combining many types of seismological data to create sharper images of Earth's interior.

The farmers in Minnesota have a point when they wonder what an "earthquake sensor" could detect in an area where there are no earthquakes. The answer is that the seismometers record distant earthquakes, such as those on the Pacific Ring of Fire on the opposite side of the planet, and ambient noise, caused by activity such as powerful storms slamming into the Jersey Shore.

Shen has seasoned the mix with several other measurements that can be extracted from the seismic record as well. By inverting all of these data functions simultaneously within a Bayesian statistical framework, he is able to obtain much clearer images of Earth's interior than one type of data alone would produce, together with estimates of the probability that the images are correct.

Not just a scar, a keloid scar

What have the scientists learned about the rift?

"When you pull apart a continent, like a piece of taffy, it starts to stretch and to thin," said Michael Wysession, professor of earth and planetary sciences and a member of the SPREE team. "And as it sags, the dip fills with low-density sediment.

"So if you go over a rift with a gravity sensor, you expect to find a negative gravity anomaly. Mass should be missing. But that's not what happened with the Midcontinent Rift. Instead of being thinner than the surrounding crust, it is thicker.

"We know that lava comes out at rifts," Wysession said. "The East African rift zone, for example, includes a number of active and dormant volcanoes, such as Mount Kilimanjaro. But the Midcontinent Rift was flooded with lava, and as it sank under the weight of the cooling basaltic rock, even more lava flowed into the depression.

"A huge volume of lava erupted here," Wysession said. "It was perhaps the largest outflowing of lava in our planet's history. And then, after the eruptions ended, the area was compressed by mountain building event to its east, thickening the scar by squeezing it horizontally.

Shen published images of the rift made with USArray data in the Journal of Geophysical Research 2013. But at that time, he had only sparse coverage in the rift's vicinity. At the 2016 GSA meeting he will present images made with both USArray and SPREE data (especially many more "receiver functions," a type of seismic data that is particularly sensitive to seismic boundaries) that show what lies beneath the rift more clearly.

Miles beneath the Earth's surface, there is a seismic boundary called the Mohorovičić discontinuity, or Moho. At the Moho, seismic waves hit higher density material and suddenly accelerate. But beneath the rift, Shen said, the Moho is blurred rather than sharp. "Its structure has been destroyed," he said.

He also sees evidence of something called magmatic underplating. "We think magma might have trapped, or stalled out, at the Moho or within the crust during its rise to the surface," he said. This might explain why the Moho is so disrupted, although Shen can think of alternative explanations and expects there to be lively discussions at the GSA.

He compares images of the Midcontinent Rift made with the SPREE array to images of the Rio Grande rift made with a similar seismic array called La Ristra. The La Ristra images show that the Rio Grande rift is thinner than the surrounding crust, not thicker. The Moho is clear and rises rather than sinks under the rift.

"I think we're looking at different stages of rifting," Shen said. The Rio Grande Rift is still active, still opening, but the Midcontinent Rift is already dead and has been squeezed shut.

Wiens commented that the tremendous outpouring of magma at the Midcontinent Rift might also have disrupted its structure, making it look different from other rifts.

"My goal," Shen said, "is to provide basic seismic models of interesting tectonic regions like this one for geologists, geochemists and scientists from other disciplines to use -- to help them interpret their results and also help the public to better understand the story of the land they live on."

Rural Minnesota is already onboard. "Some landowners were quite interested in what we were doing," Wiens said. "We got into one or two small town newspapers. 'So-and-so now has a seismometer on his farm,' the headline would read."

Story Source: Materials provided by Washington University in St. Louis. Original written by Diana Lutz.

Journal Reference: Washington University in St. Louis. "Dense arrays of seismometers are letting scientists get a clearer look at a giant scar that underlies the American Midwest." ScienceDaily. ScienceDaily, 28 September 2016. <www.sciencedaily.com/releases/2016/09/160928094313.htm>.

Earthquake risk: New fault discovered in earthquake-prone Southern California region

A swarm of nearly 200 small earthquakes that shook Southern California residents in the Salton Sea area last week raised concerns they might trigger a larger earthquake on the southern San Andreas Fault. At the same time, scientists from Scripps Institution of Oceanography at the University of California San Diego and the Nevada Seismological Laboratory at the University of Nevada, Reno published their recent discovery of a potentially significant fault that lies along the eastern edge of the Salton Sea.

The presence of the newly mapped Salton Trough Fault, which runs parallel to the San Andreas Fault, could impact current seismic hazard models in the earthquake-prone region that includes the greater Los Angeles area. Mapping of earthquake faults provides important information for earthquake rupture and ground-shaking models, which helps protect lives and reduce property loss from these natural hazards.

The National Science Foundation (NSF)-funded study appears in the Oct. 2016 issue of the journal *Bulletin of the Seismological Society of America*.

"To aid in accurately assessing seismic hazard and reducing risk in a tectonically active region, it is crucial to correctly identify and locate faults before earthquakes happen," said Valerie Sahakian, a Scripps alumna, and lead author of the study.

The research team used a suite of instruments, including multi-channel seismic data, ocean-bottom seismometers, and light detection and ranging, or lidar, to precisely map the deformation within the various sediment layers in and around the sea's bottom. They imaged the newly identified strike-slip fault within the Salton Sea, just west of the San Andreas Fault.

"The location of the fault in the eastern Salton Sea has made imaging it difficult and there is no associated small seismic events, which is why the fault was not detected earlier," said Scripps geologist Neal Driscoll, the lead principal investigator of the NSF-funded project, and coauthor of the study. "We employed the marine seismic equipment to define the deformation patterns beneath the sea that constrained the location of the fault."

Recent studies have revealed that the region has experienced magnitude-7 earthquakes roughly every 175 to 200 years for the last thousand years. A major rupture on the southern portion of the San Andreas Fault has not occurred in the last 300 years.

"The extended nature of time since the most recent earthquake on the Southern San Andreas has been puzzling to the earth sciences community," said Nevada State Seismologist Graham Kent, a coauthor of the study and former Scripps researcher. "Based on the deformation patterns, this new fault has accommodated some of the strain from the larger San Andreas system, so without having a record of past earthquakes from this new fault, it's really difficult to determine whether this fault interacts with the southern San Andreas Fault at depth or in time."

The findings provide much-needed information on the intricate structure of earthquake faults beneath the sea and what role it may play in the earthquake cycle along the southern end of the San Andreas Fault. Further research will help provide information into how the newly identified fault interacts with the southern San Andreas Fault, which may offer new insights into the more than 300-year period since the most recent earthquake.

"We need further studies to better determine the location and character of this fault, as well as the hazard posed by this structure," said Sahakian, currently a postdoctoral fellow at the U.S. Geological Survey's Earthquake Science Center. "The patterns of deformation beneath the sea suggest that the newly identified fault has been long-lived and it is important to understand its relationship to the other fault systems in this geologically complicated region."

Scripps researcher Alistair Harding and Nevada Seismological Laboratory seismologist and outreach specialist Annie Kell also contributed to the study.

Story Source: Materials provided by Scripps Institution of Oceanography.

Journal Reference: Valerie Sahakian, Annie Kell, Alistair Harding, Neal Driscoll, Graham Kent. Geophysical Evidence for a San Andreas Subparallel Transtensional Fault along the Northeastern Shore of the Salton Sea. *Bulletin of the Seismological Society of America*, 2016; 106 (5): 1963 DOI: 10.1785/0120150350.

Life in ancient oceans enabled by erosion from land

As scientists continue finding evidence for life in the ocean more than 3 billion years ago, those ancient fossils pose a paradox. Organisms, including the single-celled bacteria living in the ocean at that early date, need a steady supply of phosphorus, but "it's very hard to account for this phosphorus unless it is eroding from the continents," says Aaron Satkoski, a scientist in the geoscience department at the University of Wisconsin-Madison. "So that makes it really hard to explain the fossils we see at this early era."

Satkoski, who is first author of a new report on ocean chemistry from this remote period, says the conventional wisdom of geology has envisioned an oceanic planet, with little or no land above the waves. "Starting back in the 1960s, for various reasons people claimed there was very little continental mass, and so there wasn't enough weathering to affect the chemistry of the ocean. But there wasn't much real data from more than 3 billion years ago to support that."

Discoveries of fossil remains of bacteria from over 3 billion years ago have changed that picture, says Satkoski. "But if there was life in the ocean, you need some amount of continental weathering taking place to deliver phosphorus so the organisms can live."

The major influences on ocean chemistry today are hydrothermal flow (hot water that has circulated through the crust) and surface weathering (the river transport of material eroded from land into the ocean).

To evaluate each influence 3.26 billion years ago, geoscience Professor Clark Johnson and Satkoski collected samples from South Africa and compared isotopes in two forms of a rock called barite. The cemented granules had formed in the water, then fused after dropping to the ocean floor.

A solid, or bladed, type of barite had formed at the ocean floor. Johnson, Satkoski and colleague Brian Beard assumed that the granular rock would reflect ocean water chemistry, and therefore any eroded, continental material. The bladed barite would represent a mix of ocean chemistry and hydrothermal flow. The study hinged on precise measurements of isotopes -- atoms that are chemically identical but that have different masses. Knowing that strontium derived from land shows a slightly higher ratio of strontium 87 than strontium derived from hydrothermal circulation, the scientists compared isotopes in each type of barite.

The result was a nearly infinitesimal -- but still significant -- difference in the isotope ratios, signifying that the granular barite indeed was derived from sediment eroded from land. In other words, a significant amount of erosion was taking place 3.26 billion years ago.

Their report, just published online by *Earth and Planetary Science Letters*, pushes back the first solid date for large-scale continental erosion by 400 million years.

"It's a guess how much of the planet's surface was land, but it could be as high as two-thirds of the area of today's continents," says Johnson, who leads the NASA Astrobiology Institute at the University of Wisconsin. "Some previous estimates had no continents at all."

"When people were thinking about ocean chemistry, it was always centered on hydrothermal flow, but there was little data," Johnson says. "We are trying to put some data into the equation."

The finding about continents jibes with evidence from igneous rocks -- those sourced in hot, molten rock -- which indicated that the surface became rigid enough to support mountain belts, which would have eroded, during this period. "Now that we have a more complete picture, the story becomes more coherent," Satkoski says.

The result also meshes with climate data, as intense continental weathering could result from an increase in carbon dioxide in the atmosphere. Although the sun was relatively cold at that time, the oceans were not frozen, Satkoski says. "That suggests there was more greenhouse gas in the atmosphere, which would produce a warmer climate combined with increased weathering, because carbon dioxide creates carbonic acid and acid rain, which speeds chemical weathering."

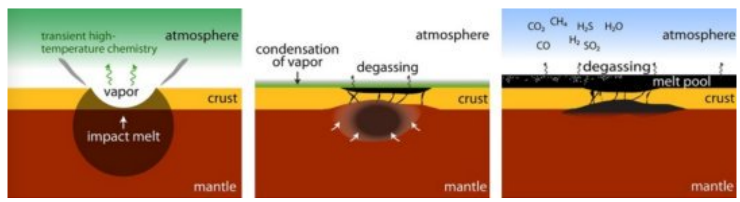
The presence of continents also indicates that the broad, slow movements of plate tectonics had started at this distant time. "Conventional wisdom says Earth had few continents because it did not have plate tectonics, which is how continents are made," Satkoski says. "Our evidence says the opposite." Overall, the result provides a satisfying unification of diverse streams of evidence, Johnson says. "We are moving toward an explanation for the presence of life, and the nutrients in the ocean, and why Earth was not frozen. They seem to fit together, but this is a very different picture of the early Earth than we had just 20 years ago.

Story Source: Materials provided by University of Wisconsin–Madison.

Journal Reference: Aaron M. Satkoski, Donald R. Lowe, Brian L. Beard, Max L. Coleman, Clark M. Johnson. **A high continental weathering flux into Paleoarchean seawater revealed by strontium isotope analysis of 3.26 Ga barite**. *Earth and Planetary Science Letters*, 2016; 454: 28 DOI: 10.1016/j.epsl.2016.08.032.

Possible solution to 'faint young Sun paradox'

Primordial asteroid bombardment triggered atmospheric warming capable of sustaining liquid water



SwRI scientists created a new model for impact-generated outgassing on the early Earth. A large impact creates a transient high temperature atmosphere. Within a thousand years, the atmosphere condenses, while deep-seated, impact-generated melt spreads across the surface. The model shows how pools of lava could release gases and create a greenhouse effect that warmed the planet.

Credit: Image courtesy of Southwest Research Institute

In the first billion years of Earth's history, the planet was bombarded by primordial asteroids, while a faint Sun provided much less heat. A Southwest Research Institute-led team posits that this tumultuous beginning may have ultimately fostered life on Earth, particularly in terms of sustaining liquid water.

"The early impacts caused temporary, localized destruction and hostile conditions for life. But at the same time, they had a long-term beneficial effect in stabilizing surface temperatures and delivering key elements for life as we know it," said Dr. Simone Marchi, a senior research scientist at SwRI's Planetary Science Directorate in Boulder, Colo. He is the lead author of a paper, "Massive Impact-induced Release of Carbon and Sulfur Gases in the Early Earth's Atmosphere," recently published in the journal *Earth and Planetary Science Letters*. The paper addresses a major problem, one of the outstanding mysteries in the history of the solar system and Earth -- the faint young Sun paradox.

"Atmospheric and surface conditions during the first billion years of Earth's history are poorly understood due to the scarcity of geological and geochemical evidence," said Marchi. However, ancient zircon crystals in sedimentary rocks provide evidence that our planet had liquid oceans, at least intermittently, during this earliest period. His team created a new model for impact-generated outgassing on the early Earth, showing how a resulting greenhouse effect could have counterbalanced the weak light from the infant Sun enough to sustain liquid water.

The findings could be key to understanding how life started on Earth despite the faint young Sun and havoc caused by collisions. Studies of other stars, as well as theoretical modeling, have shown that Sun-like stars begin their life about 20 to 30 percent fainter in visible wavelengths than the Sun is at present. They gradually increase in luminosity over time.

"Today Earth is in the 'Goldilocks zone,' where liquid water can exist on its surface," said Marchi. Referencing the fairy tale about the three little bears, the Goldilocks zone is an orbit around a star where it's not too hot, nor too cold, for liquid water. Liquid water is generally considered a key ingredient for life. When the Sun was much fainter, the Earth with its present atmospheric composition would have been frozen solid. If the oceans were frozen, life may not have formed.

The most straightforward explanation would be a massive atmospheric greenhouse effect, from either carbon dioxide or methane, or both. Previous work has speculated that volcanic outgassing or impact-vaporized materials could have released greenhouse gases. Marchi's team proposes a novel, more efficient mechanism As the planet was pummeled by primordial asteroids -- some larger than 100 kilometers in diameter -- impacts would melt large volumes of rock, creating temporary lakes of lava. These pools of lava could have released large quantities of carbon dioxide to the atmosphere.

"This early heavy bombardment could have been responsible for the large greenhouse effect needed to maintain warmer conditions, which may have been conducive to the early start for life on Earth," said Marchi. "The bombardment also delivered large quantities of sulfur, one of the most important elements for life."

Story Source: Materials provided by Southwest Research Institute.

Journal Reference: S. Marchi, B.A. Black, L.T. Elkins-Tanton, W.F. Bottke. Massive impact-induced release of carbon and sulfur gases in the early Earth's atmosphere. *Earth and Planetary Science Letters*, 2016; 449: 96 DOI: 10.1016/j.epsl.2016.05.032.

Outrageous heads led to outrageously large dinosaurs

Theropod dinosaur skulls showing unornamented (Acrocanthosaurus NCMS 14345, left) and ornamented (Cryolophosaurus FMNH PR 1821, right) styles.

Credit: Cryolophosaurus photo courtesy of Dr. Peter Makovicky, Acrocanthosaurus photo by Christophe Hendrickx

Tyrannosaurus rex and other large meat-eating theropods were the biggest baddies on the prehistoric block, and ornaments on their heads could help us figure out why. New research from North Carolina State University shows that theropod dinosaur species with bony crests, horns and knobs evolved to giant body sizes 20 times faster than those species lacking such embellishments. Additionally, the research shows that theropod dinosaurs most closely related to birds abandoned the hard ornaments strategy of their ancestors and likely used feathers for visual communication.

Most large theropods -- in fact 20 of the largest 22 species like *T. rex* and *Allosaurus* -- have bony bumps or crests on their heads. Paleontologists hypothesize that the accoutrements served as socio-sexual display mechanisms -- a way for the dinosaurs to signal to one another for mating, territory or defense purposes.

Terry Gates, lecturer in NC State's Department of Biological Sciences and research adjunct at the North Carolina Museum of Natural Sciences, wondered if there was a correlation between the development of cranial ornamentation and rapid gains in size. Along with colleague Lindsay Zanno, also of NC State and the NC Museum of Natural Sciences, and Montana State University's Chris Organ, Gates examined the fossils of 111 ornamented and unornamented theropods and compared their size increases over time.

Using observational data and computer modeling, the researchers found that for theropods weighing under 36 kg (about 80 pounds) bony cranial ornamentation did not evolve. Above that threshold, 20 of the 22 largest theropods had ornamentation. And it turns out that once a theropod species developed some style of head display, subsequent species would take large leaps toward gigantic body sizes every 4 to 6 million years. Large theropod lineages containing species without ornamentation -- such as *Acrocanthosaurus* -- did not achieve giantism as rapidly as their ornamented brethren.

"We were surprised to find such a strong relationship between ornaments and huge body size in theropods," Gates explains. "Something about their world clearly favored bling and big bods."

The researchers also looked at the lineage of dinosaurs that led to modern birds -- including maniraptoriforms like *Velociraptor*, *Ornithomimus* and *Falcarius*. These dinosaurs never acquired bony head displays (except the parrot-like oviraptors) despite the fact that many of them weighed much more than the 36 kg threshold for gaining such ornamentation. This led the researchers to wonder why the closest relatives to birds were defying the pattern observed for other theropod dinosaurs.

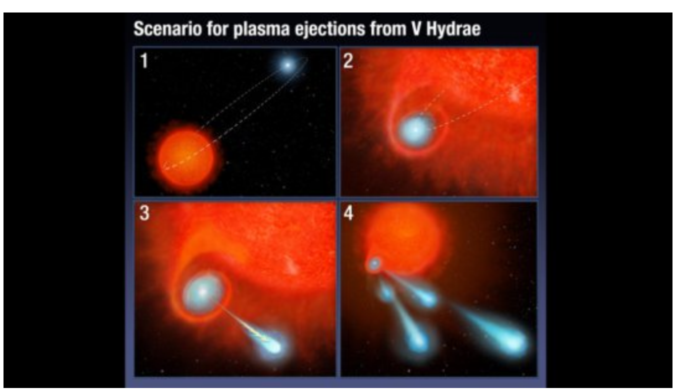
"The best explanation is that the long stiff feathers, which originated in this group of dinosaurs and were similar to modern bird feathers, could perform equally well as social signals when compared to the bony displays in *T. rex* or *Dilophosaurus*," Gates surmises.

Zanno agrees. "Our work supports the idea that vaned feathers were great communication tools from the get-go and may have helped large bird-like theropods sidestep the bother of skeletal bells and whistles," she says.

Story Source: Materials provided by North Carolina State University.

Journal Reference: Terry A. Gates, Chris Organ, Lindsay E. Zanno. Bony cranial ornamentation linked to rapid evolution of gigantic theropod dinosaurs. *Nature Communications*, 2016; 7: 12931 DOI: 10.1038/ncomms12931.

Hubble detects giant 'cannonballs' shooting from star



This four-panel graphic illustrates how the binary-star system V Hydrae is launching balls of plasma into space. Credit: NASA, ESA, and A. Feild (STScI)

Great balls of fire! NASA's Hubble Space Telescope has detected superhot blobs of gas, each twice as massive as the planet Mars, being ejected near a dying star. The plasma balls are zooming so fast through space it would take only 30 minutes for them to travel from Earth to the moon. This stellar "cannon fire" has continued once every 8.5 years for at least the past 400 years, astronomers estimate.

The fireballs present a puzzle to astronomers, because the ejected material could not have been shot out by the host star, called V Hydrae. The star is a bloated red giant, residing 1,200 light-years away, which has probably shed at least half of its mass into space during its death throes. Red giants are dying stars in the late stages of life that are exhausting the nuclear fuel that makes them shine. They have expanded in size and are shedding their outer layers into space.

The current best explanation suggests the plasma balls were launched by an unseen companion star. According to this theory, the companion would have to be in an elliptical orbit that carries it close to the red giant's puffed-up atmosphere every 8.5 years. As the companion enters the bloated star's outer atmosphere, it gobbles up material. This material then settles into a disk around the companion, and serves as the launching pad for blobs of plasma, which travel at roughly a half-million miles per hour.

This star system could be the archetype to explain a dazzling variety of glowing shapes uncovered by Hubble that are seen around dying stars, called planetary nebulae, researchers say. A planetary nebula is an expanding shell of glowing gas expelled by a star late in its life.

"We knew this object had a high-speed outflow from previous data, but this is the first time we are seeing this process in action," said Raghvendra Sahai of NASA's Jet Propulsion Laboratory in Pasadena, California, lead author of the study. "We suggest that these gaseous blobs produced during this late phase of a star's life help make the structures seen in planetary nebulae."

Hubble observations over the past two decades have revealed an enormous complexity and diversity of structure in planetary nebulae. The telescope's high resolution captured knots of material in the glowing gas clouds surrounding the dying stars. Astronomers speculated that these knots were actually jets ejected by disks of material around companion stars that were not visible in the Hubble images. Most stars in our Milky Way galaxy are members of binary systems. But the details of how these jets were produced remained a mystery.

"We want to identify the process that causes these amazing transformations from a puffed-up red giant to a beautiful, glowing planetary nebula," Sahai said. "These dramatic changes occur over roughly 200 to 1,000 years, which is the blink of an eye in cosmic time."

Sahai's team used Hubble's Space Telescope Imaging Spectrograph (STIS) to conduct observations of V Hydrae and its surrounding region over an 11-year period, first from 2002 to 2004, and then from 2011 to 2013. Spectroscopy decodes light from an object, revealing information on its velocity, temperature, location and motion.

The data showed a string of monstrous, superhot blobs, each with a temperature of more than 17,000 degrees Fahrenheit (9,400 degrees Celsius) -- almost twice as hot as the surface of the sun. The researchers compiled a detailed map of the blobs' locations, allowing them to trace the first behemoth clumps back to 1986. "The observations show the blobs moving over time," Sahai said. "The STIS data show blobs that have just been ejected, blobs that have moved a little farther away, and blobs that are even farther away." STIS detected the giant structures as far away as 37 billion miles (60 million kilometers) away from V Hydrae, more than eight times farther away than the Kuiper Belt of icy debris at the edge of our solar system is from the sun.

The blobs expand and cool as they move farther away, and are then not detectable in visible light. But observations taken at longer, sub-millimeter wavelengths in 2004, by the Submillimeter Array in Hawaii, revealed fuzzy, knotty structures that may be blobs launched 400 years ago, the researchers said.

Based on the observations, Sahai and his colleagues Mark Morris of the University of California, Los Angeles, and Samantha Scibelli of the State University of New York at Stony Brook developed a model of a companion star with an accretion disk to explain the ejection process.

"This model provides the most plausible explanation because we know that the engines that produce jets are accretion disks," Sahai explained. "Red giants don't have accretion disks, but many most likely have companion stars, which presumably have lower masses because they are evolving more slowly. The model we propose can help explain the presence of bipolar planetary nebulae, the presence of knotty jet-like structures in many of these objects, and even multipolar planetary nebulae. We think this model has very wide applicability."

A surprise from the STIS observation was that the disk does not fire the monster clumps in exactly the same direction every 8.5 years. The direction flip-flops slightly, from side-to-side to back-and-forth, due to a possible wobble in the accretion disk. "This discovery was quite surprising, but it is very pleasing as well because it helped explain some other mysterious things that had been observed about this star by others," Sahai said.

Astronomers have noted that V Hydrae is obscured every 17 years, as if something is blocking its light. Sahai and his colleagues suggest that due to the back-and-forth wobble of the jet direction, the blobs alternate between passing behind and in front of V Hydrae. When a blob passes in front of V Hydrae, it shields the red giant from view.

"This accretion disk engine is very stable because it has been able to launch these structures for hundreds of years without falling apart," Sahai said. "In many of these systems, the gravitational attraction can cause the companion to actually spiral into the core of the red giant star. Eventually, though, the orbit of V Hydrae's companion will continue to decay because it is losing energy in this frictional interaction. However, we do not know the ultimate fate of this companion."

The team hopes to use Hubble to conduct further observations of the V Hydrae system, including the most recent blob ejected in 2011. The astronomers also plan to use the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile to study blobs launched over the past few hundred years that are now too cool to be detected with Hubble. The team's results appeared in the August 20, 2016, issue of The Astrophysical Journal.

The Hubble Space Telescope is a project of international cooperation between NASA and the European Space Agency. NASA's Goddard Space Flight Center in Greenbelt, Maryland, manages the telescope. The Space Telescope Science Institute (STScI) in Baltimore, Maryland, conducts Hubble science operations. STScI is operated for NASA by the Association of Universities for Research in Astronomy in Washington, D.C.

Story Source: Materials provided by NASA/Jet Propulsion Laboratory.

Journal Reference: R. Sahai, S. Scibelli, M. R. Morris. **High-Speed Bullet Ejections During The Agb-To-Planetary Nebula Transition:Hstobservations Of The Carbon Star, V Hydrae**. The Astrophysical Journal, 2016; 827 (2): 92 DOI: 10.3847/0004-637X/827/2/92.

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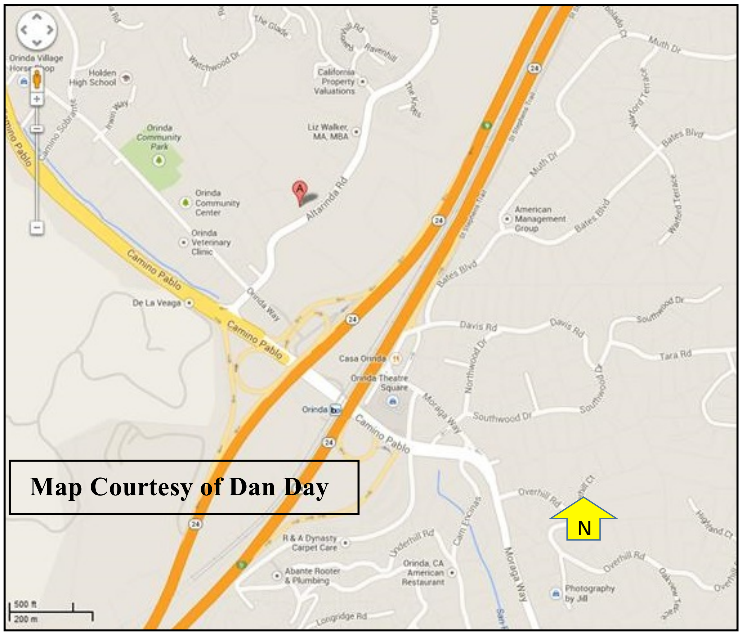

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