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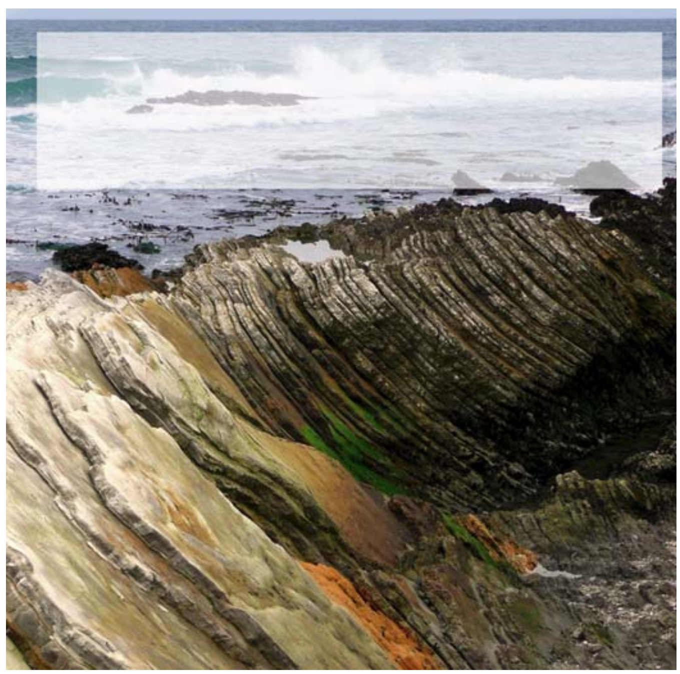
MEETING ANNOUNCEMENT

THIS IS YOUR REMINDER -

THERE IS NO MEETING THIS MONTH DUE TO THE -

2013 SPE Western Regional / Pacific Section AAPG Joint Technical Conference in Monterey, California; April 20–25, 2013



Please follow these links to the PSAAPG / SPE websites:
http://psaapg.org/upcoming-events/

https://sites.google.com/site/wnar2013/

Conference Online Registration Deadline is April 15

NCGS 2012 – 2013 Calendar

April 19 to 25 April 2013 No April NCGS Meeting!
Pacific Section AAPG Convention
Information and Registration:
http://psaapg.org/upcoming-events/
Monterey, CA

May 29, 2013 NCGS Dinner Meeting
Results from the Mars Science Laboratory Rover Curiosity's Geological Investigations of the Surface of Mars
Dr. David F. Blake, Principal Investigator, Mars Science Laboratory Rover Curiosity, NASA Ames Research Center

June 26, 2013
Dr. Lester McKee and Sarah Pearce, San Francisco Estuary Institute
TBA

Upcoming NCGS Events

Do you have a place you've wanted to visit for the geology? Let us know. We're definitely interested in ideas. For those suggestions, or for questions regarding, field trips, please contact Tridib Guha at: **TridibGuha@yahoo.com**.

Summer 2013 — ***Geology of the Golden Gate Headlands;*** **Dr. William Elder, Golden Gate National Recreation Area**

August 16, 17, 18, 2013
Friday – Sunday — ***Lassen Volcanic National Park – a wonderland of volcanoes and thermal features*** **Dr. Patrick Muffler, U.S. Geological Survey, Geologist Emeritus**

See attached field trip announcements

Peninsula Geologic Society

Upcoming meetings

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.

Bay Area Science

(http://www.bayareascience.org/)

This website provides a free weekly emailed newsletter consisting of an extensive listing of local science based activities (evening lectures, classes, field trips, hikes, and etc).

Association of Engineering Geologists San Francisco Section

Upcoming Events

Meeting locations rotate between San Francisco, the East Bay, and the South Bay. Please check the website for current details. To download meeting details and registration form go to: http://www.aegsf.org/.

USGS Evening Public Lecture Series

The USGS Evening Public Lecture Series events are free and are intended for a general public audience that may not be familiar with the science being discussed. Monthly lectures are usually scheduled for the last Thursday evening of each month during most of the year but are occasionally presented on the preceding Thursday evening to accommodate the speakers. For more information on the lectures, including a map of the lecture location (Building 3, 2nd floor; Conference Room A) go to: http://online.wr.usgs.gov/calendar/

Garniss Curtis Memorial Update

The March newsletter contained an article about the passing of **Garniss Curtis**. Doris Sloan has provided us with a correction on the date of the memorial and a web link with further details. A celebration of Garniss Curtis' life will be held on Sept. 29, 2013, from 2 pm to 5 pm at the UC Berkeley Faculty Club. Details can be found at http://www.garnisscurtis.net.

ANNOUNCEMENT of NCGS FIELD TRIP One Saturday This Summer

"Geology of the Golden Gate Headlands"
Leader: Dr. William Elder,
Golden Gate National Recreation Area

Abstract: From ancient mid-ocean ridges and hotspots, to seamounts and subduction zones and finally to roaring

glacial rivers and drifting sands, learn how geology has shaped the Golden Gate headlands and provided habitat for the diverse biota of Golden Gate National Recreation Area. This field trip focuses on the rocks of the headlands just north and south of the Golden Gate. Exposed in dramatic sea cliffs, these rocks not only form a spectacular backdrop for the Golden Gate Bridge, but also provide a detailed record of Pacific basin and active margin tectonics spanning nearly 200 million years. The significance of these rocks also goes beyond the geologic story that they tell, for these and other rocks of the Franciscan Complex associated with them were central to the development of our current understanding of subduction zones processes and the mechanics of accretionary prisms. Join geologist and park ranger Will Elder for the day as we view exquisitely folded chert, ore-grade manganese beds, textbook pillow basalts, tortured serpentinite cliffs and more, while we explore and reveal stories from the past, present and future of the Golden Gate Headlands.

Biography: Dr. Will Elder has been an interpretive park ranger at Golden Gate National Recreation Area for 15 years, and before that he was a geologist and paleontologist with the U.S. Geological Survey. Will first became acquainted with the local geology as an Earth Sciences student at College of Marin and U.C. Santa Cruz. Following a stint with the geophysics group at USGS in Menlo Park, Will went to University of Colorado, where his dissertation project focused on a major marine extinction that occurred 100 million years ago, during the warmest time in the Earth's history. Will returned to the USGS at Menlo Park as the Mesozoic invertebrate paleontologist, where he studied many of the fossils known from the Franciscan Complex and published on a wide variety of paleontologic and sedimentologic topics. Today, will is back thinking about a warm Earth and focusing much of his time on communicating climate change issues to the public.

THIS FIELD TRIP WILL BE LIMITED TO 40 PEOPLE
(Due to very limited parking carpool/vanpool is a must)

To reserve a spot please send an email to **Tridib Guha;** e-mail: tridibguha@yahoo.com

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ANNOUNCEMENT of NCGS FIELD TRIP

Friday, Saturday, Sunday August 16, 17 & 18, 2013

"Lassen Volcanic National Park – a wonderland of volcanoes and thermal features"

Leader: Dr. Patrick Muffler;
US Geological Survey, Geologist Emeritus

The field trip will summarize 37 years of USGS volcanic and hydrothermal investigations in and around Lassen Volcanic National Park, primarily by Mike Clynne and Patrick Muffler. The area will be visited is presented on 1:50,000 Geologic Map of Lassen Volcanic National Park and Vicinity (USGS Scientific Investigations Map 2899, published in 2010).

We will circulate attendees list for carpooling to the meeting place.

THIS FIELD TRIP WILL BE LIMITED TO 42 PEOPLE
Field Trip Logistics and cost - In preparation

Time & Meeting Place: August 16, 2013, 6:00 pm; southwest corner Sunvalley Mall Parking lot, Concord We will depart on a chartered bus to Redbluff. We will spend the night in a motel at Redbluff. Next day after the field trip spend the night at Chester in a motel. Sunday we return to Concord.

To reserve a spot please send an email to **Tridib Guha;** e-mail: tridibguha@yahoo.com

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NCGS DINNER MEETING

"RESULTS FROM THE MARS SCIENCE LABORATORY ROVER CURIOSITY's GEOLOGICAL INVESTIGATIONS OF THE SURFACE OF MARS"

Dr. David F. Blake,
Principal Investigator
Mars Science Laboratory Rover Curiosity
NASA Ames Research Center

Wednesday May 29, 2013
6:00 PM at Orinda Masonic Center
(Reservations are required by May 24, 2013, Limit 100 persons)
We are sorry but we will not be able to accommodate "walk-ins"

Stepping out of our normal routine, the **Northern California Geological Society** is pleased to announce this *special dinner and evening* with **Dr. David Blake**. For this unique event, planned for our normal monthly meeting date, but starting one-half hour early, we are planning in typical NCGS style, a **Back Forty Texas BBQ dinner consisting of Pork Ribs and BBQ Chicken, Tossed Green Salad, BBQ Beans, Fresh Corn Cobettes. For**

vegetarian dinners a deluxe veggie burger will be served in place of BBQ. Desert will include assorted cookies and brownies. We may be again serving wines from California specials (90 pts +). Please also note that a vegetarian option is available if notified ahead (please see the registration form below).

Abstract: Geological Investigations of the surface of the Mars

One of the principal goals of the Mars Science Laboratory rover Curiosity is to identify and characterize the early habitable environments of Mars, as recorded in the stratified rocks and soil of Gale crater. The suite of instruments aboard Curiosity will make measurements useful for determining the presence and lateral/vertical distribution of hydrated phases, the mineralogy and "preservation potential" of sediments and rocks, and the identity and isotopic composition of volatiles, organics, and other carbon-containing molecules, should they be present.

Curiosity's mast and arm instruments allow it to perform essentially the same functions as a field geologist would on Earth. Once a location is characterized, Curiosity's sample acquisition system can deliver samples of rock or soil to the "laboratory" instruments CheMin and SAM. CheMin, a powder X-ray Diffraction /X-ray Fluorescence (pXRD/XRF) instrument, determines the quantitative mineralogy of scooped soils and powders obtained from drilled rocks. Hydrated minerals can be identified, along with whole-rock mineralogy for characterizing the environment of formation and preservation potential for organic molecules. SAM consists of a gas chromatograph – mass spectrometer (GC-MS), and a tunable laser spectrometer (TLS). SAM will accept the same powdered rock and soil samples as CheMin, and will identify and measure trace organic carbon, as well as the elemental and isotopic composition of volatiles released during heating.

The overall progress of the mission, as well as mineralogical results from an analysis of the soil of an aeolian bedform ("Rocknest soil") and from a drilled bedrock sample ("Yellowknife Bay") will be described.

Speaker Biography:

Dr. David Blake is the Principal Investigator of the CheMin XRD/XRF instrument on the Mars Science Laboratory rover Curiosity, and is a member of the Principal Science Group that directs the activities of Curiosity during its 2-year mission.

He came to Ames Research Center as a NRC postdoctoral fellow, and became a research scientist in the Exobiology Branch at Ames in 1989. He was the Exobiology Branch Chief from 2000-2004. In nearly 25 years of research at Ames, he has studied astrophysical ices, interplanetary dust, Mars meteorites, lunar soils and stratopheric roots. He received a B.S.in Biological Sciences from Stanford University in 1973. After a stint in the US Navy, he attended graduate school at the University of Michigan, where he received a PhD in Geology & Mineralogy in 1983.

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Dinner Logistics

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Meeting Details: **Social Hour**: 6:00 – 7:00 pm; **Dinner:** 7:00 – 8:00 pm **Presentation**: 8:00 – open

Time: May 29, 2013, 6:00 pm, Orinda Masonic Center 9 Altarinda Road, Orinda, CA

Cost: **$25/person**

REGISTRATION FORM (Dr. David Blake Dinner)

Name:_________________________________

E-mail:_________________________________

Phone (day):________________

Phone (cell) _________________

Dinner: Regular:________ Vegetarian:

(Please check one) Check Amount:

Please mail a check made out to **NCGS** to:
Tridib Guha, 5016 Gloucester Lane, Martinez, CA 94553

Questions: e-mail: tridibguha@yahoo.com Phone: (925) 451-1999

How Earthquake Damage Can Impact Building Fire Safety Performance

Mar. 11, 2013 — Damage to building structural elements, elevators, stairs, and fire protection systems caused by the shaking from a major earthquake can play a critical role in the spread of fire and hamper the ability of occupants to evacuate, and impede fire departments in their emergency response operations. These are among the conclusions of a groundbreaking study of post-earthquake building fire performance conducted in 2012 by researchers in the Department of Fire Protection Engineering at Worcester Polytechnic Institute (WPI).

Flames shoot from the five-story test building during WPI's post-earthquake fire tests. (Credit: Image courtesy of Worcester Polytechnic Institute)

"When the ground stops shaking after a major earthquake, the damage may have just begun," said Brian Meacham, associate professor of fire protection engineering at WPI and principal investigator for the post-earthquake fire study. "Historically, post-earthquake fires have been as devastating if not more devastating, than the seismic events that preceded them. In fact, the largest peacetime urban conflagrations (in San Francisco in 1906 and in Tokyo in 1923) were post-earthquake fires. More recently, fire caused significant damage following the 1995 Kobe, Japan, earthquake."

While the danger of widespread quake-related fires is well-known, much less is known about how earthquakes affect the ability of individual buildings to withstand fire or how building fires evolve and spread in the minutes and hours after a quake strikes, Meacham said. "Although considerable research has been undertaken with respect to the performance of structural systems in quakes, research aimed at understanding and quantifying the performance of nonstructural systems and post-earthquake fire performance of buildings has been severely lacking."

To help close that knowledge gap, WPI spent last year participating in an unprecedented study of the effects of earthquakes and post-earthquake fires on a full-scale building. Sponsored by the National Science Foundation and a host of industrial partners, and led by researchers at the University of California, San Diego (UCSD), the study centered on a five-story building constructed atop the world's first large outdoor, high-performance shake table, located at the Englekirk Structural Engineering Center at UCSD. A principal focus of the study was the performance of critical facilities, including hospitals and data centers.

The building was outfitted with a working elevator, a full-size interior staircase, heating, ventilating and air conditioning system components, electrical equipment, fire protection systems, and a mock medical suite, intensive care unit, medical storage room, server room, and residential space. The third floor was configured for fire testing, including complete partition walls and ceiling systems, firestop materials at joints and through partitions, a fire door, a fire sprinkler system, and a smoke detection system.

The researchers subjected the building to a series of simulated earthquakes, ranging from 6.7 on the Richter scale (the magnitude of the 1994 quake in Northridge, Calif.) to 7.9 (representing the 2002 earthquake in Denali, Alaska), while a team of engineers from UC San Diego monitored the building's performance through more than 500 channels of data from a wide range of sensors. After each simulated earthquake, Meacham and his student researchers entered the building to document the state of the active and passive fire systems and to conduct pressure tests to determine if the shaking compromised the integrity of the third-floor rooms, possibly creating openings that could allow smoke and flames to move between compartments.

After the seismic testing was complete, the WPI team conducted a series of six live fire tests in four spaces on the third floor. They ignited pans of heptane, a liquid fuel that burns hot enough to simulate a fully engaged compartment fire. Using temperature probes and video cameras, the researchers assessed how damage from the simulated earthquakes affected the ability of the active and passive fire protection systems to contain fires and prevent the spread of smoke.

Here are some of the impacts on fire and life safety systems that Meacham and his team documented following the largest earthquake motion and post-earthquake fire tests:

- Structural damage on the second and third levels was significant; while the building didn't collapse, it had to be shored up to support gravity loading prior to the fire testing.
- Damage to the building's interior and exterior wall and ceiling systems created openings through which smoke and flames could spread;

debris from the walls and ceilings became obstacles that would have hampered the evacuation of occupants or the movements of firefighters.

- A number of doors were unable to be opened or closed (open doors allow fire to spread; stuck doors can cut off escape routes or hinder the movements of first responders).
- Access to the upper floors was cut off when the staircase became detached from the landing and distortion of the elevator doors and frame on some levels made the elevator unusable. During the fire tests, smoke and hot gasses entered the elevator shaft through the open doors, spreading smoke to other floors and raising temperatures to dangerous levels.
- Most of the active and passive fire protection systems, including the sprinkler system, the heat-activated fire door, fire dampers, and fire stop materials, performed well.

"We are pleased with what we were able to learn in this initial full-scale test of post-earthquake fires," Meacham said. "Through this research, we have begun to build a base of knowledge that will allow us to design more resilient buildings and building systems, and provide better protection to people, property, and mission. But there is much more to do and a lot more we can learn in subsequent studies."

Meacham said he would like to conduct additional laboratory and large-scale studies that will broaden the base of knowledge, encompassing, for example, different construction techniques and different glazing systems; that will gather additional types of information, including heat flux, flow velocity, and visual records of smoke movement and fire growth; and that will compare fire performance before and after earthquake damage.

Story Source: The above story is reprinted from materials provided by Worcester Polytechnic Institute.

Journal Reference: Worcester Polytechnic Institute (2013, March 11). How earthquake damage can impact building fire safety performance. *ScienceDaily*.

How to Repel an Earthquake

Science Now

Sean Treacy; February 14, 2013

Want to protect buildings from earthquakes? Turn the surrounding ground into Swiss cheese. Scientists have for the first time shown that a grid of holes in the ground can act as a kind of seismic wall, a development that could lead to technologies that protect buildings from the dangerous tremors of earthquakes.

"It's very cool stuff," says Ulf Leonhardt, a theoretical physicist at the University of St. Andrews in the United Kingdom who was not involved with the study. "It's a step toward manipulating seismic waves and done in a genius way."

For more than a decade, scientists have been manipulating electromagnetic waves with metamaterials—assemblages of conductors and insulators patterned at length scales shorter than the waves themselves. Metamaterials can change the speed and direction of the waves in bizarre ways, and researchers have used them to funnel light around objects in the first generation of invisibility cloaks. The successes of those experiments raise another question: Can researchers also manipulate the nonelectromagnetic seismic waves set in motion by an earthquake? Computer models imagining a larger metamaterial seemed to suggest they could. But the new work, by a team of engineers from the French ground improvement company Ménard and physicists from Aix Marseille Université in France, is the first to put a seismic wave cloak to the test.

Shaken up. Large metamaterials could help prevent earthquake damage; Credit: Katorisi/Creative Commons

The scientists created their jumbo-sized metamaterial in August 2012 by drilling holes in a thick bed of silt and clay near the city of Grenoble in the French Alps. The cylindrical holes stretched down about 5 meters into the earth, but were also skinny, only 32 centimeters wide. They were arranged in a rectangular grid of three rows of 10 holes each. The holes changed the density and stiffness of the earth and, thus, the speed and direction of vibrations rippling through the ground, forming a seismic metamaterial. The scientists then shook the earth on one side of the grid using a vibrating soil-compacting machine that they had placed underground. That machine created 50 seismic surface waves per second with a wavelength of 1.56 meters—about the same as the distance between the holes, though shorter than typical wavelengths from earthquakes.

Sensors placed throughout the site showed that the waves couldn't get past the grid of holes, bouncing off of it instead, the researchers report in a paper posted on the arXiv online preprint server. The waves just barely got by the second row of holes and couldn't even touch the third row, leaving the ground on the other side unshaken.

The large scale of the experiment really stands out, says Steven Cummer, an engineer at Duke University in Durham, North Carolina. "What this group is reporting, I think that is a pretty important step."

However, the work is not yet the earth-shaking advance that will render earthquakes harmless, says Nicholas Fang, a mechanical engineer at the Massachusetts Institute of Technology in Cambridge. Fang says the new experiment is "exciting" but notes that it does not address the complexities of the interactions between temblors and buildings. For example, at the experiment site the waves had to navigate only fine silty clay, whereas a real earthquake's seismic waves would run through a broad variety of rock, influencing their strength and direction. "I think there's great potential, but we don't have a complete answer for [protecting buildings] yet."

Earth Is 'Lazy' When Forming Faults Like Those Near San Andreas

Apr. 3, 2013 — Geoscientist Michele Cooke and colleagues at the University of Massachusetts Amherst take an uncommon, "Earth is lazy" approach to modeling fault development in the crust that is providing new insights into how faults grow. In particular, they study irregularities along strike-slip faults, the active zones where plates slip past each other such as at the San Andreas Fault of southern California.

Geoscientist Michele Cooke, left, and summer intern Jessica Moody set up the clay table to where experiments investigate irregularities along strike-slip faults such as California's San Andreas. (Credit: Image courtesy of University of Massachusetts at Amherst)

Until now there has been a great deal of uncertainty among geologists about the factors that govern how new faults grow in regions where one plate slides past or over another around a bend, says Cooke. In their study published in an early online edition of the *Journal of Structural Geology*, she and colleagues offer the first systematic exploration of fault evolution around fault bends based on modeling in a clay box.

Testing ideas about how Earth's crust behaves in real time is impossible because actions unfold over many thousands of years, and success in reconstructing events after the fact is limited. A good analog for laboratory experiments has been a goal for decades. "Geologists don't agree on how the earth's crust handles restraining bends along faults. There's just a lack of evidence. When researchers go out in the field to measure faults, they can't always tell which one came first, for example," Cooke says.

Unlike most geoscience researchers, she takes a mechanical efficiency approach to study dynamic fault systems' effectiveness at transforming input energy into force and movement. For example, a straight fault is more efficient at accommodating strain than a bumpy fault. For this reason Cooke is very interested in how the efficiency of fault bends evolves with increasing deformation.

Her data suggest that at restraining bends, the crust behaves in accord with "work minimization" principles, an idea she dubs the "Lazy Earth" hypothesis. "Our approach offers some of the first system-type evidence of how faults evolve around restraining bends," she says.

Further, Cooke's UMass Amherst lab is one of only a handful worldwide to use a relatively new modeling technique that uses kaolin clay rather than sand to better understand the behavior of Earth's crust.

For these experiments, she and colleagues Mariel Schottenfeld and Steve Buchanan, both undergraduates at the time, used a clay box or tray loaded with kaolin, also known as china clay, prepared very carefully so its viscosity scales to that of the earth's crust. When scaled properly, data from clay experiments conducted over several hours in a table-top device are useful in modeling restraining bend evolution over thousands of years and at the scale of tens of kilometers.

Cooke says sand doesn't remember faults the way kaolin can. In an experiment of a bend in a fault, sand will just keep forming new faults. But clay will remember an old fault until it's so inefficient at accommodating the slip that a new fault will eventually form in a manner much more similar to what geologists see on the ground.

Another innovation Cooke and colleagues use is a laser scan to map the clay's deformation over time and to collect quantitative data about the system's efficiency. "It's a different approach than the conventional one," Cooke acknowledges. "I think about fault evolution in terms of work and efficiency. With this experiment we now have compelling evidence from the clay box experiment that the development of new faults increases the efficiency of the system. There is good evidence to support the belief that faults grow to improve efficiency in the Earth's crust as well. "

"We're moving toward much more precision within laboratory experiments," she adds. "This whole field is revolutionized in past six years. It's an exciting time to be doing this sort of modeling. Our paper demonstrates the mastery we now can have over this method."

The observation that a fault's active zone can shift location significantly over 10,000 years is very revealing, Cooke says, and has important implications for understanding seismic hazards. The more geologists understand fault development, the better they may be able to predict earthquake hazards and understand Earth's evolution, she points out.

Funding for this work came from grants from the National Science Foundation and the Southern California Earthquake Center.

Story Source: The above story is reprinted from materials provided by University of Massachusetts at Amherst.

Journal Reference: Michele L. Cooke, Mariel T. Schottenfeld, Steve W. Buchanan. **Evolution of fault efficiency at restraining bends within wet kaolin analog experiments**. *Journal of Structural Geology*, 2013; DOI: 10.1016/j.jsg.2013.01.010

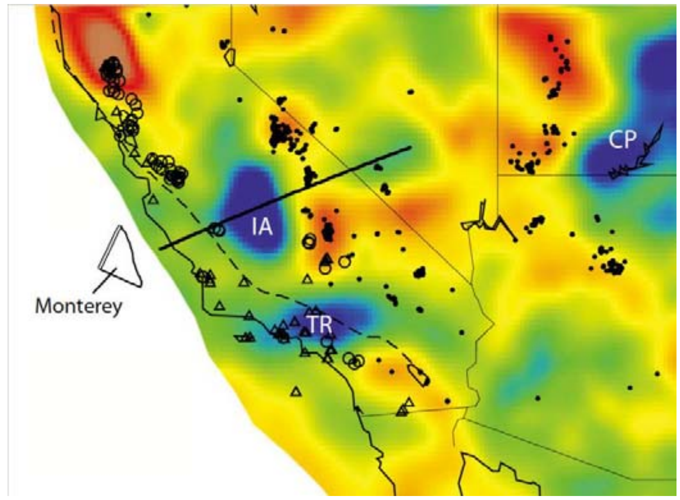
Slabs of Ancient Tectonic Plate Still Lodged Under California

Mar. 18, 2013 — The Isabella anomaly -- indications of a large mass of cool, dehydrated material about 100 kilometers beneath central California -- is in fact a surviving slab of the Farallon oceanic plate. Most of the Farallon plate was driven deep into the Earth's mantle as the Pacific and North American plates began converging about 100 million years ago, eventually coming together to form the San Andreas fault.

Large chunks of an ancient tectonic plate that slid under North America millions of years ago are still present under parts of central California and Mexico, according to new research led by Brown University geophysicists.

Around 100 million years ago, the Farallon oceanic plate lay between the converging Pacific and North American plates, which eventually came together to form the San Andreas fault. As those plates converged, much of the Farallon was subducted underneath North America and eventually sank deep into the mantle. Off the west coast of North America, the Farallon plate fragmented, leaving a few small remnants at the surface that stopped subducting and became part of the Pacific plate.

But this new research suggests that large slabs from Farallon remain attached to these unsubducted fragments. The researchers used seismic tomography and other data to show that part of the Baja region and part of central California near the Sierra Nevada mountains sit atop "fossil" slabs of the Farallon plate.



Mostly gone, not forgotten. The Isabella anomaly (IA, above), is at the same depth (ca. 100 km) as other fragments of the Farallon plate under Oregon and Washington, is on a line with fragments off the California coast, and has a similar seismic tomography signature. (Credit: Forsyth lab/Brown University)

"Many had assumed that these pieces would have broken off quite close to the surface," said Brown geophysicist Donald Forsyth, who led the research with Yun Wang, a former Brown graduate student now at the University of Alaska. "We're suggesting that they actually broke off fairly deep, leaving these large slabs behind."

The findings are published in the *Proceedings of the National Academy of Sciences*.

Geologists had known for years about a "high velocity anomaly" in seismic tomography data near the Sierra Nevada mountains in California. Seismic tomography measures the velocity of seismic waves deep underground. The speed of the waves provides information about the composition and temperature of the subsurface. Generally, slower waves mean softer and hotter material; faster waves mean stiffer and cooler material.

The anomaly in California, known as the Isabella anomaly, indicated that a large mass of relatively cool and dehydrated material is present at a depth of 100 to 200 kilometers below the surface. Just what that mass was wasn't known, but there were a few theories. It was often explained by a process called delamination. The crust beneath the eastern part of the mountains is thin and the mantle hot, indicating that part of the lithospheric plate under the mountains had delaminated -- broken off. The anomaly, scientists thought, might be the signature of that sunken hunk of lithosphere, which would be cooler and dryer than the surrounding mantle.

But a few years ago, scientists detected a new anomaly under the Mexico's Baja Peninsula, due east of one of the known coastal remains of the Farallon plate. Because of its proximity to the Farallon fragment, Forsyth and Wang thought it was very likely that the anomaly represented an underground extension of the fragment.

A closer look at the region showed that there are high-magnesium andesite deposits on the surface near the eastern edge of the anomaly. These kinds of deposits are volcanic rocks usually associated with the melting of oceanic crust material. Their presence suggests that the eastern edge of the anomaly represents the spots where Farallon finally gave way and broke off, sending andesites to the surface as the crust at the end of the subducted plate melted.

That led Forsyth and his colleagues to suspect that perhaps the Isabella anomaly in California might also represent a slab still connected to an unsubducted fragment of the Farallon plate. So they re-examined the tomography data along the entire West Coast. They compared the Baja and Isabella anomalies to anomalies associated with known Farallon slabs underneath Washington and Oregon.

The study found that all of the anomalies are strongest at the same depth -- right around 100 kilometers. And all of them line up nearly due east of known fragments from Farallon.

"The geometry was the kicker," Forsyth said. "The way they line up just makes sense."

The findings could force scientists to re-examine the tectonic history of western North America, Forsyth said. In particular, it forces a rethinking of the delamination of the Sierra Nevada, which had been used to explain the Isabella anomaly.

"However the Sierra Nevada was delaminated," Forsyth said, "it's probably not in the way that many people had been thinking."

His research colleague asnd co-author Brian Savage of the University of Rhode Island agrees. "This work has radically changed our understanding of the makeup of the west coast of North America," Savage said. "It will cause a thorough rethinking of the geological history of North America and undoubtedly many other continental margins.""

The work was supported by the National Science Foundation. Other authors on the paper were Brown graduate student Christina Rau, Brown undergraduate Nina Carriero, Brandon Schmandt from the University of Oregon, and James Gaherty from Columbia University.

Story Source: The above story is reprinted from materials provided by Brown University.

Journal Reference: Yun Wang, Donald W. Forsyth, Christina J. Rau, Nina Carriero, Brandon Schmandt, James B. Gaherty, and Brian Savage. **Fossil slabs attached to unsubducted fragments of the Farallon plate**. *PNAS*, March 18, 2013 DOI: 10.1073/pnas.1214880110

2011 Oklahoma Temblor: Wastewater Injection Spurred Biggest Earthquake Yet, Study Says

Mar. 26, 2013 — A new study in the journal *Geology* is the latest to tie a string of unusual earthquakes, in this case, in central Oklahoma, to the injection of wastewater deep underground. Researchers now say that the magnitude 5.7 earthquake near Prague, Okla., on Nov. 6, 2011, may also be the largest ever linked to wastewater injection. Felt as far away as Milwaukee, more than 800 miles away, the quake -- the biggest ever recorded in Oklahoma--destroyed 14 homes, buckled a federal highway and left two people injured. Small earthquakes continue to be recorded in the area.

The recent boom in U.S. energy production has produced massive amounts of wastewater. The water is used both in hydrofracking, which cracks open rocks to release natural gas, and in coaxing petroleum out of conventional oil wells. In both cases, the brine and chemical-laced water has to be disposed of, often by injecting it back underground elsewhere, where it has the potential to trigger earthquakes. The water linked to the Prague quakes was a byproduct of oil extraction at one set of oil wells, and was pumped into another set of depleted oil wells targeted for waste storage.

Scientists have linked a rising number of quakes in normally calm parts of Arkansas, Texas, Ohio and Colorado to below-ground injection. In the last four years, the number of quakes in the middle of the United States jumped 11-fold from the three decades prior, the authors of the Geology study estimate. Last year, a group at the U.S. Geological Survey also attributed a remarkable rise in small- to mid-size quakes in the region to humans. The risk is serious enough that the National Academy of Sciences, in a report last year called for further research to "understand, limit and respond" to induced seismic events. Despite these studies, wastewater injection continues near the Oklahoma earthquakes.

A 2011 magnitude 5.7 quake near Prague, Okla., apparently triggered by wastewater injection, buckled U.S. Highway 62. (Credit: John Leeman)

The magnitude 5.7 quake near Prague was preceded by a 5.0 shock and followed by thousands of aftershocks. What made the swarm unusual is that wastewater had been pumped into abandoned oil wells nearby for 17 years without incident. In the study, researchers hypothesize that as wastewater replenished compartments once filled with oil, the pressure to keep the fluid going down had to be ratcheted up. As pressure built up, a known fault --known to geologists as the Wilzetta fault--jumped. "When you overpressure the fault, you reduce the stress that's pinning the fault into place and that's when earthquakes happen," said study coauthor Heather Savage, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory.

The amount of wastewater injected into the well was relatively small, yet it triggered a cascading series of tremors that led to the main shock, said study co-author Geoffrey Abers, also a seismologist at Lamont-Doherty. "There's something important about getting unexpectedly large earthquakes out of small systems that we have discovered here," he said. The observations mean that "the risk of humans inducing large earthquakes from even small injection activities is probably higher" than previously thought, he said.

Hours after the first magnitude 5.0 quake on Nov. 5, 2011, University of Oklahoma seismologist Katie Keranen rushed to install the first three of several dozen seismographs to record aftershocks. That night, on Nov. 6, the magnitude 5.7 main shock hit and Keranen watched as her house began to shake for what she said felt like 20 seconds. "It was clearly a significant event," said Keranen, the Geology study's lead author. "I gathered more equipment, more students, and headed to the field the next morning to deploy more stations."

Keranen's recordings of the magnitude 5.7 quake, and the aftershocks that followed, showed that the first Wilzetta fault rupture was no more than 650 feet from active injection wells and perhaps much closer, in the same sedimentary rocks, the study says. Further, wellhead records showed that after 13 years of pumping at zero to low pressure, injection pressure rose more than 10-fold from 2001 to 2006, the study says.

The Oklahoma Geological Survey has yet to issue an official account of the sequence, and wastewater injection at the site continues. In a statement responding to the paper, Survey seismologist Austin Holland said the study showed the earthquake sequence could have been triggered by the injections. But, he said, "it is still the opinion of those at the Oklahoma Geological Survey that these earthquakes could be naturally occurring. There remain many open questions, and more scientific investigations are underway on this sequence of earthquakes and many others within the state of Oklahoma."

The risk of setting off earthquakes by injecting fluid underground has been known since at least the 1960s, when injection at the Rocky Mountain Arsenal near Denver was suspended after a quake estimated at magnitude 4.8 or greater struck nearby -- the largest tied to wastewater disposal until the one near Prague, Okla. A series of similar incidents have emerged recently. University of Memphis seismologist Stephen Horton in a study last year linked a rise in earthquakes in north-central Arkansas to nearby injection wells. University of Texas, Austin, seismologist Cliff Frohlich in a 2011 study tied earthquake swarms at the Dallas-Fort Worth Airport to a brine disposal well a third of a mile away. In Ohio, Lamont-Doherty seismologists Won-Young Kim and John Armbruster traced a series of 2011 earthquakes near Youngstown to a nearby disposal well. That well has since been shut down, and Ohio has tightened its waste-injection rules.

Wastewater injection is not the only way that people can touch off quakes. Evidence suggests that geothermal drilling, impoundment of water behind dams, enhanced oil recovery, solution salt mining and rock quarrying also can trigger seismic events. (Hydrofracking itself is not implicated in significant earthquakes; the amount of water used is usually not enough to produce substantial shaking.) The largest known earthquakes attributed to humans may be the two magnitude 7.0 events that shook the Gazli gas fields of Soviet Uzbekistan in 1976, followed by a third magnitude 7.0 quake eight years later. In a 1985 study in the Bulletin of the Seismological Society of America, Lamont-Doherty researchers David Simpson and William Leith hypothesized that the quakes were human-induced but noted that a lack of information prevented them from linking the events to gas production or other triggers. In 2009, a geothermal energy project in Basel, Switzerland, was canceled after development activities apparently led to a series of quakes of up to magnitude 3.4 that caused some $8 million in damage to surrounding properties.

In many of the wastewater injection cases documented so far, earthquakes followed within days or months of fluid injection starting. In contrast, the Oklahoma swarm happened years after injection began, similar to swarms at the Cogdell oil field in West Texas and the Fort St. John area of British Columbia.

The Wilzetta fault system remains under stress, the study's authors say, yet regulators continue to allow injection into nearby wells. Ideally, injection should be kept away from known faults and companies should be required to provide detailed records of how much fluid they are pumping underground and at what pressure, said Keranen. The study authors also recommend sub-surface monitoring of fluid pressure for earthquake warning signs. Further research is needed but at a minimum, "there should be careful monitoring in regions where you have injection wells and protocols for stopping pumping even when small earthquakes are detected," said Abers. In a recent op-ed in the Albany (N.Y.) Times Union, Abers argued that New York should consider the risk of induced earthquakes from fluid injection in weighing whether to allow hydraulic fracturing to extract the state's shale gas reserves.

The study was also coauthored by Elizabeth Cochran of the U.S. Geological Survey.

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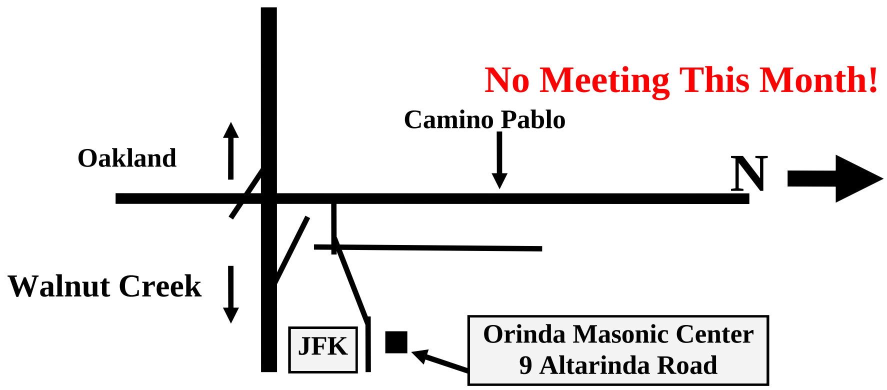

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