# NORTHERN CALIFORNIA GEOLOGICAL SOCIETY




## MEETING ANNOUNCEMENT

**DATE:** **Wednesday, April 24, 2019**

**LOCATION:** **Orinda Masonic Center, 9 Altarinda Rd., Orinda (see map on back page)**

**TIME:** **6:30 – 7:00 p.m.: Social; 7:00 p.m.: Presentation**

**SPEAKER:** ***Owen Anfinson, Ph.D.***
***Sonoma State University,***
***Rohnert Park, California***

**TOPIC:** ***"To See the World in a Grain of Sand: Utilizing detrital heavy minerals to reconstruct California's sedimentary history"***

"To see a World in a Grain of Sand
And a Heaven in a Wild Flower,
Hold Infinity in the palm of your hand
And Eternity in an hour" – William Blake

Poet William Blake envisioned a world inside a grain of sand, but when these words were written in 1803 they lacked the technology to unlock the true secrets of that beautifully complex world. These sand grains hold a rich and deep story that may hold the key to reconstructing the tectonic history of California. We are becoming increasingly effective at unlocking the immense amount of information contained within a single mineral grain. These mineral grains are weathered out of rocks to become the sand of our beaches, rivers, and deserts. We call these sand grains "detrital minerals," and the heavy, or high-density, detrital minerals have been my trade for the past 14 years.

I was first introduced to the power of detrital heavy minerals at Washington State University while tracking sediment deposited by catastrophic glacial floods at the end of the last ice age. I became increasingly involved in the use of a particular detrital heavy mineral, zircon. Detrital zircon is taking its place as a mineral juggernaut in the world of geology. By incorporating uranium (U) into its crystal structure, while excluding lead (Pb), zircon can be dated with a very high level of precision and accuracy utilizing the U-Pb decay system.

During my presentation for the Northern California Geological Society I will focus on the use of detrital zircon geochronology to address issues within the Salinian Terrane and Franciscan Complex of Northern


***(continued on last page)***

# NCGS 2018 – 2019 Calendar

**May 29, 2019** ***Dinner meeting*** ***6:00 pm***

Dr. Tanya Atwater, Prof. Emerita, UC, Santa Barbara

***Topic to be announced***

**June 26, 2019** **7:00 pm**

Dr. Jonathan Lilien, Chevron

***Environmental Aspects of Oil & Gas Production in California***

## New Paper on Geology of San Francisco Available on Association of Environmental & Engineering Geologists Website

A new paper has been issued as part of the Association of Environmental & Engineering Geologists (AEG), Geology of the Cities of the World Series. The paper is titled "**Geology of San Francisco, California, United States of America**," and can be downloaded for free at https://www.aegweb.org/.

This paper summarizes the geologic history of the San Francisco Bay Area and the engineering characteristics of geologic units, geologic hazards, water resources, infrastructure development, environmental issues, and geologic issues associated with major engineering structures built in San Francisco.

The paper was recently released to coincide with the September 2018 Annual Meeting of AEG and the International AEG in San Francisco. Kenneth A. Johnson and Greg W. Bartow co-edited the 189-page paper.

## NCGS Outreach: Rock Donation

At the March 27, 2019 meeting, Mark Sorensen donated a very nice suite of rocks and minerals for the NCGS Outreach Rock and Mineral Collection (see photo). These are (clockwise from top left):

- Travertine tufa, Mono Lake, CA: a $CaCO_3$ precipitate in lake water. Collected about 100 feet above the current lake level.
- Basalt with granitic (xenolith) inclusions from Cinko Lake area, Sonoma Pass, CA
- Feldspar phenocrysts in granite matrix from the Young Lakes area, near eastern edge of Yosemite National Park
- Blueschist from south of Jenner, CA.

Not shown is a very nice cassiterite (tin ore: $SnO_2$) crystal specimen from Alaska

We'd like to improve our rock display with 3 to 4-inch hand samples (not necessarily local) of elements (we have sulfur) and simple minerals composed of sulfur, iron, lead or copper, and one or two complex minerals. Additionally, we need larger hand-samples of other Bay Area minerals and rocks that we don't have (e.g., diopside, barite, unusual serpentinite, plutonic igneous rocks, and conglomerate). If anyone cares to donate such, it would be well appreciated.

For any rock/mineral donations and/or if you'd like to volunteer for our outreach program, please contact our Outreach Chair, Mark Petrofsky at: mpetrof @ hotmail.com.

## NCGS Field Trips

Starting the spring (and we hope for some dryness!), we plan to hold several 2019 trips on or near Mount Diablo, to focus on and coordinate with our 75th anniversary GSA volume on its geology. Watch for announcements.

## The Seventy-Fifth Anniversary of the Northern California Geological Society

Yes, it has been 75 years since the NCGS began as an outgrowth of a genial gathering, over brews, of geologists from a variety of mostly petroleum exploration companies, in Rio Vista in 1944. Please join us in 2019 as we celebrate this landmark anniversary, and come to as many of our events as you can! We are targeting the end of the calendar year for the release ***The Geology of Mount Diablo*** in a special publication of the Geological Society of America. Also this year, we plan to run several **field trips** on and near the mountain, and will keep you posted on those opportunities. Other ways to participate and/or re-connect with your fellow members are to attend any or all of our **upcoming**

**meetings** for which we have some very notable speakers slated, and to assist at any of our **outreach opportunities**, where you can meet and encourage the next generation of geologists and their parents!

### CGS SPECIAL REPORT 230
### Geological Gems of California State Parks

California's state parks encompass a wide range of the state's diverse natural resources, including some significant geologic features and history. However, although the geology of California tells a fascinating story of the state's evolution, it's a story that is not well known or understood by most park visitors. To make this story more available to the general public, the State Parks' Natural Resources Division collaborated with the Department of Conservation's California Geological Survey to produce a report entitled, "Geological Gems of California State Parks" also known as "Geo Gems". The report highlights notable geologic features in 55 California state parks - geologic wonders that illustrate the legacy and continuing evolution of California. For details: https://www.parks.ca.gov/?page_id=29631.

## AAPG Delegate Opportunity

If any AAPG Member will be attending the annual meeting in San Antonio, May 19-22, and would like to represent NCGS at the annual House of Delegates meeting on May 19, please contact Don Lewis at donlewis@comcast.net. Don is one of our two Delegates to the House and is unable to attend this year due to a competing college graduation.

**WE HAVE A FACEBOOK GROUP! FIND US ON FACEBOOK @NCGEOLSOC AND TWITTER @NORCALGEOSOC**

**Check out our updated NCGS Website at http://ncgeolsoc.org/.** We have posted many older field trip guidebooks for free downloading, and we describe the process for purchasing newer guidebooks. The website includes a list of upcoming meetings, information on our scholarship program, a list of useful web links, and list of NCGS officers.

## UC Berkeley Earth & Planetary Science Weekly Seminar Series

Interesting seminars are presented at 141 McCone Hall (usually) on Thursdays at 4 pm for most of the academic year, from late August through early May. For an updated list of seminars, go to http://eps.berkeley.edu/events/seminars.

NCGS members are invited our next **Board of Directors meeting,** on **April 27** at the APTIM office at 4005 Port Chicago Highway. Board meetings are generally held at 8:30 am on a Saturday in January, May, and September, and are open to all NCGS members. Please contact Greg Bartow if you would like to attend, at gregbartow@yahoo,com.

## 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. The next lecture will be given Thursday, April 18 by Kristin Byrd, USGS Research Physical Scientist, on ***The Story of California's Changing Ecosystems: As Observed from Space***. For more information on the lectures, and for a map of the location, go to: https://online.wr.usgs.gov/calendar/.

## NCGS Member Registration

A quick reminder: Have you updated your membership by sending in your registration form and fee? See page 13 for a blank registration form, and mail it in as indicated, or drop it off with Barbara Matz at the check-in desk at the next meeting.

## 66-million-year-old deathbed linked to dinosaur-killing meteor

**Fossil site preserves animals killed within minutes of meteor impact**

*ScienceDaily, March 29, 2019*

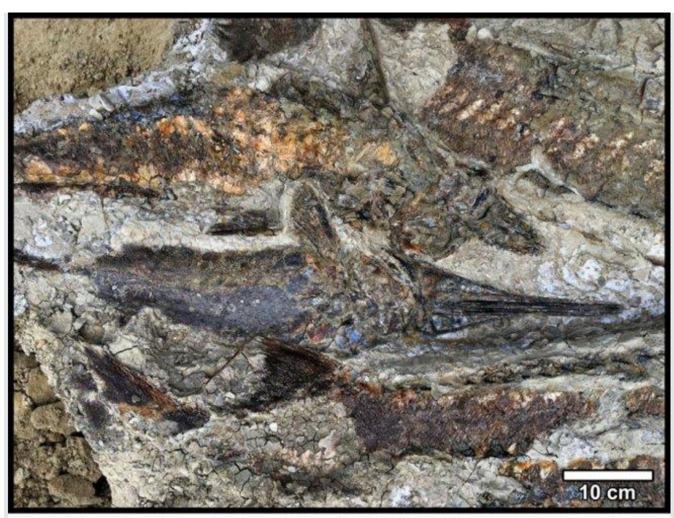


Image information: intertangled mass of articulated fish from the Tanis inundation surge deposit

Fossilized fish piled one atop another, suggesting that they were flung ashore and died stranded together on a sand bar after the wave from the seiche withdrew.

Credit: Photo courtesy of Robert DePalma

The beginning of the end started with violent shaking that raised giant waves in the waters of an inland sea in what is now North Dakota. Then, tiny glass beads began to fall like birdshot from the heavens. The rain of glass was so heavy it may have set fire to much of the vegetation on land. In the water, fish struggled to breathe as the beads clogged their gills.

The heaving sea turned into a 30-foot wall of water when it reached the mouth of a river, tossing hundreds, if not thousands, of fresh-water fish -- sturgeon and paddlefish -- onto a sand bar and temporarily reversing the flow of the river. Stranded by the receding water, the fish were pelted by glass beads up to 5 millimeters in diameter, some beads burying themselves inches deep in the mud. The torrent of rocks, like fine sand, and small glass beads continued for another 10 to 20 minutes before a second large wave inundated the shore and covered the fish with gravel, sand and fine sediment, sealing them from the world for 66 million years.

This unique, fossilized graveyard -- fish stacked one atop another and mixed in with burned tree trunks, conifer branches, dead mammals, mosasaur bones, insects, the partial carcass of a Triceratops, marine microorganisms called dinoflagellates and snail-like marine cephalopods called ammonites -- was unearthed by paleontologist Robert DePalma over the past six years in the Hell Creek Formation, not far from Bowman, North Dakota. The evidence confirms a suspicion that nagged at DePalma in his first digging season during the summer of 2013 -- that this was a killing field laid down soon after the asteroid impact that eventually led to the extinction of all ground-dwelling dinosaurs. The impact at the end of the Cretaceous Period, the so-called K-T boundary, exterminated 75 percent of life on Earth.

"This is the first mass death assemblage of large organisms anyone has found associated with the K-T boundary," said DePalma, curator of paleontology at the Palm Beach Museum of Natural History in Florida and a doctoral student at the University of Kansas. "At no other K-T boundary section on Earth can you find such a collection consisting of a large number of species representing different ages of organisms and different stages of life, all of which died at the same time, on the same day."

In a paper to appear next week in the journal Proceedings of the National Academy of Sciences, he and his American and European colleagues, including two University of California, Berkeley, geologists, describe the site, dubbed Tanis, and the evidence connecting it with the asteroid or comet strike off Mexico's Yucatan Peninsula 66 million years ago. That impact created a huge crater, called Chicxulub, in the ocean floor and sent vaporized rock and cubic miles of asteroid dust into the atmosphere. The cloud eventually enveloped Earth, setting the stage for Earth's last mass extinction.

"It's like a museum of the end of the Cretaceous in a layer a meter-and-a-half thick," said Mark Richards, a UC Berkeley professor emeritus of earth and planetary science who is now provost and professor of earth and space sciences at the University of Washington.

Richards and Walter Alvarez, a UC Berkeley Professor of the Graduate School who 40 years ago first hypothesized that a comet or asteroid impact caused the mass extinction, were called in by DePalma and Dutch scientist Jan Smit to consult on the rain of glass beads and the tsunami-like waves that buried and preserved the fish. The beads, called tektites, formed in the atmosphere from rock melted by the impact.

**Tsunami vs. seiche**

Richards and Alvarez determined that the fish could not have been stranded and then buried by a typical tsunami, a single wave that would have reached this previously unknown arm of the Western Interior Seaway no less than 10 to 12 hours after the impact 3,000 kilometers away, if it didn't peter out before then. Their reasoning: The tektites would have rained down within 45 minutes to an hour of the impact, unable to create mudholes if the seabed had not already been exposed.

Instead, they argue, seismic waves likely arrived within 10 minutes of the impact from what would have been the equivalent of a magnitude 10 or 11 earthquake, creating a seiche (pronounced saysh), a standing wave, in the inland sea that is similar to water sloshing in a bathtub during an earthquake. Though large earthquakes often generate seiches in enclosed bodies of water, they're seldom noticed, Richards said. The 2011 Tohoku quake in Japan, a magnitude 9.0, created six-foot-high seiches 30 minutes later in a Norwegian fjord 8,000 kilometers away.

"The seismic waves start arising within nine to 10 minutes of the impact, so they had a chance to get the water sloshing before all the spherules (small spheres) had fallen out of the sky," Richards said. "These spherules coming in cratered the surface, making funnels -- you can see the deformed layers in what used to be soft mud -- and then rubble covered the spherules. No one has seen these funnels before."

The tektites would have come in on a ballistic trajectory from space, reaching terminal velocities of between 100 and 200 miles per hour, according to Alvarez, who estimated their travel time decades ago. "You can imagine standing there being pelted by these glass spherules. They could have killed you," Richards said. Many believe that the rain of debris was so intense that the energy ignited wildfires over the entire American continent, if not around the world.

"Tsunamis from the Chicxulub impact are certainly well-documented, but no one knew how far something like that would go into an inland sea," DePalma said. "When Mark came aboard, he discovered a remarkable artifact -- that the incoming seismic waves from the impact site would have arrived at just about the same time as the atmospheric travel time of the ejecta. That was our big breakthrough."

At least two huge seiches inundated the land, perhaps 20 minutes apart, leaving six feet of deposits covering the fossils. Overlaying this is a layer of clay rich in iridium, a metal rare on Earth, but common in asteroids and comets. This layer is known as the K-T, or K-Pg boundary, marking the end of the Cretaceous Period and the beginning of the Tertiary Period, or Paleogene.

**Iridium**

In 1979, Alvarez and his father, Nobelist Luis Alvarez of UC Berkeley, were the first to recognize the significance of iridium that is found in 66 million-year-old rock layers around the world. They proposed that a comet or asteroid impact was responsible for both the iridium at the K-T boundary and the mass extinction.

The impact would have melted the bedrock under the seafloor and pulverized the asteroid, sending dust and melted rock into the stratosphere, where winds would have carried them around the planet and blotted out the sun for months, if not years. Debris would have rained down from the sky: not only tektites, but also rock debris from the continental crust, including shocked quartz, whose crystal structure was deformed by the impact.

The iridium-rich dust from the pulverized meteor would have been the last to fall out of the atmosphere after the impact, capping off the Cretaceous. "When we proposed the impact hypothesis to explain the great extinction, it was based just on finding an anomalous concentration of iridium -- the fingerprint of an asteroid or comet," said Alvarez. "Since then, the evidence has gradually built up. But it never crossed my mind that we would find a deathbed like this."

Key confirmation of the meteor hypothesis was the discovery of a buried impact crater, Chicxulub, in the Caribbean and off the coast of the Yucatan in Mexico, that was dated to exactly the age of the extinction. Shocked quartz and glass spherules were also found in K-Pg layers worldwide. The new discovery at Tanis is the first time the debris produced in the impact was found along with animals killed in the immediate aftermath of the impact.

"And now we have this magnificent and completely unexpected site that Robert DePalma is excavating in North Dakota, which is so rich in detailed information about what happened as a result of the impact," Alvarez said. "For me, it is very exciting and gratifying!"

**Tektites**

Jan Smit, a retired professor of sedimentary geology from Vrije Universiteit in Amsterdam in The Netherlands who is considered the world expert on tektites from the impact, joined DePalma to analyze and date the tektites from the Tanis site. Many were found in near perfect condition embedded in amber, which at the time was pliable pine pitch.

"I went to the site in 2015 and, in front of my eyes, he (DePalma) uncovered a charred log or tree trunk about four meters long which was covered in amber, which acted as sort of an aerogel and caught the tektites when they were coming down," Smit said. "It was a major discovery, because the resin, the amber, covered the tektites completely, and they are the most unaltered tektites I have seen so far, not 1 percent of alteration. We dated them, and they came out to be exactly from the K-T boundary."

The tektites in the fishes' gills are also a first. "Paddlefish swim through the water with their mouths open, gaping, and in this net, they catch tiny particles, food particles, in their gill rakers, and then they swallow, like a whale shark or a baleen whale," Smit said. "They also caught tektites. That by itself is an amazing fact. That means that the first direct victims of the impact are these accumulations of fishes."

Smit also noted that the buried body of a Triceratops and a duck-billed hadrosaur proves beyond a doubt that dinosaurs were still alive at the time of the impact.

"We have an amazing array of discoveries which will prove in the future to be even more valuable," Smit said. "We have fantastic deposits that need to be studied from all different viewpoints. And I think we can unravel the sequence of incoming ejecta from the Chicxulub impact in great detail, which we would never have been able to do with all the other deposits around the Gulf of Mexico. So far, we have gone 40 years before something like this turned up that may very well be unique," Smit said. "So, we have to be very careful with that place, how we dig it up and learn from it. This is a great gift at the end of my career. Walter sees it as the same."

**Journal Reference:** DePalma, Robert A.; Smit, Jan; Burnham, David; Kuiper, Klaudia; Manning, Phillip; Oleinik, Anton; Larson, Peter; Maurrasse, Florentin; Vellekoop, Johan; Richards, Mark A.; Gurche, Loren; Alvarez, Walter. Prelude to Extinction: a seismically induced onshore surge deposit at the KPg boundary, North Dakota. *PNAS*, 2019.

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# California's current earthquake hiatus is an unlikely pause

*ScienceDaily, April 3, 2019*

There have been no major ground rupturing earthquakes along California's three highest slip rate faults in the past 100 years. A new study published in Seismological Research Letters concludes that this current "hiatus" has no precedent in the past 1000 years.

U.S. Geological Survey researchers Glenn Biasi and Kate Scharer analyzed long paleoseismic records from the San Andreas, San Jacinto and Hayward Faults for the past 1000 years, to determine how likely it might be to have a 100-year gap in earthquakes across the three faults. They found that the gap was very unlikely -- along the lines of a 0.3% chance of occurring, given the seismic record of the past 1000 years.

The results emphasize that the hiatus is exceptional, and that the gap isn't some sort of statistical fluke created by incomplete paleoseismic records, said Biasi. The analysis also indicates that the next 100 years of California earthquakes along these faults could be a busy one, he noted. "If our work is correct, the next century isn't going to be like the last one, but could be more like the century that ended in 1918."

Between 1800 and 1918, there were eight large ground-rupturing earthquakes along the faults, including the well-known 1906 earthquake in San Francisco and the similar-sized 1857 rupture of the San Andreas in southern California, but nothing so large since.

"We know these big faults have to carry most of the [tectonic] motion in California, and sooner or later they have to slip," said Biasi. "The only questions are how they're going to let go and when."

The three faults and their major branches analyzed by the researchers accommodate the majority of the slip between the Pacific and North American plate boundary. Paleoseismic records from the faults predict that there would be three to four large ground-rupturing earthquakes (magnitude 6.5 or larger) each century.

Biasi and Scharer examined the best available paleoseismic records from sites along the three faults to determine whether the current gap could be explained by missing data, or incorrect radiocarbon dating of past earthquakes. From these data, they calculated the probability that there would be a 100-year gap in ground-rupturing earthquakes across all three faults.

"Our paper confirms that this hiatus is very improbable and it's our view that our efforts will be better spent considering explanations for this, rather than trying to bend the data to make the hiatus a 'statistically improbable but could happen' kind of thing," said Biasi.

"We're saying, no, it's not a data problem, it's not a data choice problem, it doesn't matter how you slice this," he added. "We just have not had earthquakes that past records predict that we should have had."

He likened the hiatus to what a person might see if they pulled up a chair alongside a freeway to count passing cars. "You might say that a certain number of cars per hour is kind of representative, and then something happens and you go ten minutes of seeing no cars. If it's just ten minutes, you could say it was a statistical fluke. But if the freeway stays clear of traffic for a long time, the other reason there might be no cars is that up around the bend, there's a wreck," said Biasi. "The other reason there might be no cars is that up around the bend, there's a wreck," said Biasi.

The researchers would like more seismologists to focus on the reasons -- "the wreck around the bend" -- behind the current hiatus. "We had the flurry of very large earthquakes from 1800 to 1918," Biasi said. "It's possible that among them they just wrung out -- in the sense of wringing out a dishrag -- a tremendous amount of energy out the system."

There may be stronger long-range interactions between the faults than suspected, or there may be unknown features of the mantle and lower crust below the faults that affect the probability of ground-rupturing earthquakes, he noted.

**Journal Reference:** Glenn P. Biasi, Katherine M. Scharer. The Current Unlikely Earthquake Hiatus at California’s Transform Boundary Paleoseismic Sites. Seismological Research Letters, 2019; DOI: 10.1785/0220180244.

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# Arctic warming contributes to drought

*ScienceDaily, March 27, 2019*

When the Arctic warmed after the ice age 10,000 years ago, it created perfect conditions for drought.

According to new research led by a University of Wyoming scientist, similar changes could be in store today because a warming Arctic weakens the temperature difference between the tropics and the poles. This, in turn, results in less precipitation, weaker cyclones and weaker mid-latitude westerly wind flow -- a recipe for prolonged drought.

The temperature difference between the tropics and the poles drives a lot of weather. When those opposite temperatures are wider, the result is more precipitation, stronger cyclones and more robust wind flow. However, due to the Arctic ice melting and warming up the poles, those disparate temperatures are becoming closer.

"Our analysis shows that, when the Arctic is warmer, the jet stream and other wind patterns tend to be weaker," says Bryan Shuman, a UW professor in the Department of Geology and Geophysics. "The temperature difference in the Arctic and the tropics is less steep. The change brings less precipitation to the mid-latitudes."

Shuman is a co-author of a new study that is highlighted in a paper, titled "Mid-Latitude Net Precipitation Decreased With Arctic Warming During the Holocene," published online on March 27 in *Nature*, an international weekly science journal. The print version of the article will be published April 4.

Researchers from Northern Arizona University; Universite Catholique de Louvain in Louvain-In-Neuve, Belgium; the Florence Bascom Geoscience Center in Reston, Va.; and Cornell University also contributed to the paper.

"The Nature paper takes a global approach and relates the history of severe dry periods of temperature changes. Importantly, when temperatures have changed in similar ways to today (warming of the Arctic), the mid-latitudes -- particularly places like Wyoming and other parts of central North America -- dried out," Shuman explains. "Climate models anticipate similar changes in the future."

Currently, the northern high latitudes are warming at rates that are double the global average. This will decrease the equator-to-pole temperature gradient to values comparable with the early to middle Holocene Period, according to the paper.

Shuman says his research contribution, using geological evidence, was helping to estimate how dry conditions have been in the past 10,000 years. His research included three water bodies in Wyoming: Lake of the Woods, located above Dubois; Little Windy Hill Pond in the Snowy Range; and Rainbow Lake in the Beartooth Mountains.

"Lakes are these natural recorders of wet and dry conditions," Shuman says. "When lakes rise or lower, it leaves geological evidence behind." The researchers' Holocene temperature analysis included 236 records from 219 sites. During the past 10,000 years, many of the lakes studied were lower earlier in history than today, Shuman says.

"Wyoming had several thousand years where a number of lakes dried up, and sand dunes were active where they now have vegetation," Shuman says. "Expanding to the East Coast, it is a wet landscape today. But 10,000 years ago, the East Coast was nearly as dry as the Great Plains."

The research group looked at the evolution of the tropic-to-pole temperature difference from three time periods: 100 years ago, 2,000 years ago and 10,000 years ago. For the last 100 years, many atmospheric records facilitated the analysis but, for the past 2,000 years or 10,000 years, there were fewer records available. Tree rings can help to expand studies to measure temperatures over the past 2,000 years, but lake deposits, cave deposits and glacier ice were studied to record prior temperatures and precipitation.

"This information creates a test for climate models," Shuman says. "If you want to use a computer to make a forecast of the future, then it's useful to test that computer's ability to make a forecast for some other time period. The geological evidence provides an excellent test."

The research was funded by the Science Foundation Arizona Bisgrove Scholar Award, the National Science Foundation and the state of Arizona's Technology and Research Initiative Fund administered by the Arizona Board of Regents.

**Journal Reference:** Cody C. Routson, Nicholas P. McKay, Darrell S. Kaufman, Michael P. Erb, Hugues Goosse, Bryan N. Shuman, Jessica R. Rodysill, Toby Ault. Mid-latitude net precipitation decreased with Arctic warming during the Holocene. *Nature*, 2019; DOI: 10.1038/s41586-019-1060-3.

# Earth's deep mantle flows dynamically

*ScienceDaily, March 25, 2019*

As ancient ocean floors plunge over 1,000 km into the Earth's deep interior, they cause hot rock in the lower mantle to flow much more dynamically than previously thought, finds a new UCL-led study.

The discovery answers long-standing questions on the nature and mechanisms of mantle flow in the inaccessible part of deep Earth. This is key to understanding how quickly Earth is cooling, and the dynamic evolution of our planet and others in the solar system.

"We often picture the Earth's mantle as a liquid that flows but it isn't -- it's a solid that moves very slowly over time. Traditionally, it's been thought that the flow of rock in Earth's lower mantle is sluggish until you hit the planet's core, with most dynamic action happening in the upper mantle which only goes to a depth of 660 km. We've shown this isn't the case after all in large regions deep beneath the South Pacific Rim and South America," explained lead author, Dr Ana Ferreira (UCL Earth Sciences and Universidade de Lisboa).

"Here, the same mechanism we see causing movement and deformation in the hot, pressurised rock in the upper mantle is also occurring in the lower mantle. If this increased activity is happening uniformly over the globe, Earth could be cooling more rapidly than we previously thought," added Dr Manuele Faccenda, Universita di Padova.

The study, published today in Nature Geoscience by researchers from UCL, Universidade de Lisboa, Universita di Padova, Kangwon National University and Tel Aviv University, provides evidence of dynamic movement in the Earth's lower mantle where ancient ocean floors are plunging towards the planet's core, crossing from the upper mantle (up to ~660 km below the crust) to the lower mantle (~660 to 1,200 km deep).

The team found that the deformation and increased flow in the lower mantle is likely due to the movement of defects in the crystal lattice of rocks in the deep Earth, a deformation mechanism called "dislocation creep," whose presence in the deep mantle has been the subject of debate.

The researchers used big data sets collected from seismic waves formed during earthquakes to probe what's happening deep in Earth's interior. The technique is well established and comparable to how radiation is used in CAT scans to see what's happening in the body.

"In a CAT scan, narrow beams of X-rays pass through the body to detectors opposite the source, building an image. Seismic waves pass through the Earth in much the same way and are detected by seismic stations on the opposite side of the planet to the earthquake epicentre, allowing us to build a picture of the structure of Earth's interior," explained Dr Sung-Joon Chang, Kangwon National University.

By combining 43 million seismic data measurements with dynamic computer simulations using the UK's supercomputing facilities HECToR, Archer and the Italian Galileo Computing Cluster, CINECA the researchers generated images to map how the Earth's mantle flows at depths of ~1,200 km beneath our feet.

They revealed increased mantle flow beneath the Western Pacific and South America where ancient ocean floors are plunging towards Earth's core over millions of years.

This approach of combining seismic data with geodynamic computer modelling can now be used to build detailed maps of how the whole mantle flows globally to see if dislocation creep is uniform at extreme depths.

The researchers also want to model how material moves up from the Earth's core to the surface, which together with this latest study, will help scientists better understand how our planet evolved into its present state.

"How mantle flows on Earth might control why there is life on our planet but not on other planets, such as Venus, which has a similar size and location in the solar system to Earth, but likely has a very different style of mantle flow. We can understand a lot about other planets from revealing the secrets of our own," concluded Dr Ferreira.

The study was funded by the Leverhulme Trust, NERC, the Korea Meteorlogical Administration Research and Development Program, the Progetto di Ateneo FACCPTRAT12 granted by the Università di Padova and by the ERC StG #758199 NEWTON.

**Journal Reference:** Ana M. G. Ferreira, Manuele Faccenda, William Sturgeon, Sung-Joon Chang, Lewis Schardong. Ubiquitous lower-mantle anisotropy beneath subduction zones. *Nature Geoscience*, 2019; DOI: 10.1038/s41561-019-0325-7.

# Sources and Sinks: What drives long-term climatic trends?

*ScienceDaily, March 14, 2019*

For the entire history of our species, humans have lived on a planet capped by a chunk of ice at each pole. But Earth has been ice-free for about 75 percent of the time since complex life first appeared. This variation in background climate, between partly glaciated and ice-free, has puzzled geologists for decades.

Now a team of scientists led by UC Santa Barbara's Francis Macdonald has published a study suggesting that tectonic activity may be the culprit. They found that long-term trends in Earth's climate are set by the presence or absence of collisions between volcanic arcs and continents in the tropics. The results appear in the journal *Science*.

"There've been a few hypotheses but no agreements as to why we have warmer or colder climates on these very long timescales," said Macdonald, a professor in the Department of Earth Science.

And when Macdonald says "long timescales," he's talking about 10 million-year periods, at a minimum. These are broad climatic trends, the backdrop against which natural and human-made fluctuations play out. Scientists have a relatively good understanding of what factors influence the climate on a thousand-year timescale, according to Macdonald.

On any scale, though, the primary agent of climate change is carbon dioxide ($CO_2$). The question is what factors influence the amount of $CO_2$ in atmosphere. Some processes produce $CO_2$, while others absorb it. Scientists call these sources and sinks.

The debate among geologists is whether sources or sinks affect the climate more. "Some have argued that $CO_2$ sources, like volcanism, have driven climate change on long timescales, while others have argued that, no, it's the sinks that have caused climate change on these timescales," said Macdonald.

He believes it's mostly the sinks, specifically vast deposits of rock that absorb $CO_2$ through chemical reactions. But these carbon sinks are not distributed evenly across the surface. For instance, greater Indonesia is only 1-2 percent of the Earth's exposed land area, but accounts for roughly 10 percent of the current geologic carbon sink.

The activity of these sinks depends on a number of factors. Water is important for the chemical reactions and also washes the end results away into the oceans, where they consume $CO_2$. Mountain-building increases the reactions by uplifting and exposing new rock. In flat terrain, the soil shields the underlying rock.

Rock type also plays a key role. Stone rich in iron and magnesium has simpler chemical bonds that are more easily broken down. This makes these mafic rocks, like basalt, better carbon sinks than rocks such as granite, which have more complex bonds.

Plate tectonics is what drives this geologic carbon cycle. When one tectonic plate slides under another -- usually a dense ocean plate under a continent -- the melting rock fuels a row of volcanoes on the top plate called a volcanic arc. The Cascade Range of the Pacific Northwest is one example of this.

Macdonald and his colleagues reckoned that when these volcanic arcs collide with another continent, the collision uplifts mafic rocks. These rocks are readily eroded, particularly in warm, wet, tropical latitudes, and the sediment is sent out to oceans where it consumes $CO_2$. So, he reasoned, when these collisions happen in the tropics, they drive the climate toward cooling.

"The tropics are where the rocks weather best because it's the warmest and wettest," explained coauthor Lorraine Lisiecki, an associate professor also in UC Santa Barbara's Department of Earth Science.

To test their hypothesis, the team used reconstructions of the continents and mountain-building events that scientists had built up over the past decades. This gave them an idea where and when arc-continent collisions happened. They limited themselves to the last 500 million years, since the geologic record is much less complete, and reconstructions less certain, before that time.

Temperature is harder to get a read on than geography, so the team used a simple metric: Was there ice on the poles at a given time or not? They reconstructed this information from the literature by looking at data on rocks that form only in the presence of ice. What they found was that Earth had significant ice cover during only four periods in their time window.

Combining the geographic and temperature data, the team found that over the last 500 million years, glacial climates occurred during periods of extensive collision between continents and volcanic arcs in the tropics. There was less than a 1 percent probability that the match was due to chance. "Given how many things are changing on Earth at the same time, it's amazing that it all came out really clean and matched so well," said Lisiecki.

The collisions have the added effect of shutting down volcanic arc activity, which cuts off that source of $CO_2$.

"But if it was a volcanic effect, it wouldn't matter where the volcano was," Lisiecki said. It's only the weathering effect where latitude makes a difference. And the team found a much stronger relationship between the climate and collisions that happened in the tropics, rather than those that were outside the tropics.

"These hypotheses are not necessarily entirely independent," said Macdonald, "but our analysis suggests that the strongest relationship is with the weathering piece."

Macdonald embarked on this large compilation project after several of his colleagues had pushed back on results from studies with smaller scopes. "I thought, 'You're absolutely right. We need to look at this more broadly,'" he recalled. Now the team hopes this paper challenges their colleagues to make a more rigorous case for their own hypotheses.

Macdonald and Lisiecki also know that this paper is not the last word. "The database is open," Macdonald said, "so I'm hoping that this is an iterative project. And as more constraints come online, they can be entered and the model can be refined." To that end, he is currently investigating how strong an effect rock type has on this hypothesis.

Humans have lived for hundreds of thousands of years with little concept of the dramatic changes the planet has witnessed over the eons. Although the subjects it studies are ancient, modern geology developed relatively recently. The theory of plate tectonics, for example, was not widely accepted until the 1960s. "We often think of Earth as always being like we're seeing now," said Macdonald. "But it's been a totally different planet throughout its history."

**Journal Reference:** Francis A. Macdonald, Nicholas L. Swanson-Hysell, Yuem Park, Lorraine Lisiecki, Oliver Jagoutz. Arc-continent collisions in the tropics set Earth’s climate state. *Science*, 2019; eaav5300 DOI: 10.1126/science.aav5300.

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## $CO_2$ mineralization in geologically common rocks for carbon storage

*ScienceDaily, March 8, 2019*

Humanity needs to improve when it comes to reducing carbon emissions to prevent the worst effects of climate change. If the world is to meet the IPCC's minimum target of keeping global temperature increases below 1.5 °C, every possible avenue for $CO_2$ remediation must be explored.

Geological trapping can play a major role here. Our planet's underground rocks and sediments offer a vast potential space for long-term carbon storage. To support this, a recent computational study from a Japanese-led international group at Kyushu University shows how trapped carbon dioxide can be converted into harmless minerals.

The rocks beneath the earth's surface are highly porous, and trapping involves injecting $CO_2$ into the pores after collecting it from its emission source. Although $CO_2$ is usually considered too stable to react chemically with rock, it can bind tightly to the surface by physical adsorption. Eventually it dissolves in water, forming carbonic acid, which can react with aqueous metals to form carbonate minerals.

"Mineralization is the most stable method of long-term $CO_2$ storage, locking $CO_2$ into a completely secure form that can't be re-emitted," explains Jihui Jia of the International Institute for Carbon-Neutral Energy Research (I2CNER), Kyushu University, first author of the study. "This was once thought to take thousands of years, but that view is rapidly changing. The chemical reactions are not fully understood because they're so hard to reproduce in the lab. This is where modeling comes in."

As reported in *The Journal of Physical Chemistry C*, simulations were initially run to predict what happens when carbon dioxide collides with a cleaved quartz surface -- quartz ($SiO_2$) being abundant in the earth's crust. When the simulation trajectories were played back, the $CO_2$ molecules were seen bending from their linear O=C=O shape to form trigonal $CO_3$ units bonded with the quartz.

In a second round of simulations, $H_2O$ molecules were added to mimic the "formation water" that is often present beneath oil and gas drilling sites. Intriguingly, the $H_2O$ molecules spontaneously attacked the reactive $CO_3$ structures, breaking the Si-O bonds to produce carbonate ions. Just like carbonic acid, carbonate ions can react with dissolved metal cations (such as $Mg^{2+}$, $Ca^{2+}$, and $Fe^{2+}$) to bind carbon permanently into mineral form.

Together, the simulations show that both steps of $CO_2$ mineralization -- carbonation (binding to rock) and hydrolysis (reacting with water) -- are favorable. Moreover, free carbonate ions can be made by hydrolysis, not just by dissociation of carbonic acid as was once assumed. These insights relied on a sophisticated form of molecular dynamics that models not just the physical collisions between atoms, but electron transfer, the essence of chemistry.

"Our results suggest some ways to improve geological trapping," says study lead author Takeshi Tsuji. "For quartz to capture $CO_2$, it must be a cleaved surface, so the silicon and oxygen atoms have reactive 'dangling' bonds. In real life, however, the surface might be protected by hydrogen bonding and cations, which would prevent mineralization. We need a way to strip off those cations or dehydrogenate the surface."

Evidence is growing that captured $CO_2$ can mineralize much faster than previously believed. While this is exciting, the Kyushu paper underlines how complex and delicate the chemistry can be. For now, the group recommends further studies on other abundant rocks, like basalt, to map out the role that geochemical trapping can play in the greatest technical challenge facing civilization.

**Journal Reference**: Jihui Jia, Yunfeng Liang, Takeshi Tsuji, Caetano R. Miranda, Yoshihiro Masuda, Toshifumi Matsuoka. Ab Initio Molecular Dynamics Study of Carbonation and Hydrolysis Reactions on Cleaved Quartz (001) Surface. **The Journal of Physical Chemistry C**, 2019; 123 (8): 4938 DOI: 10.1021/acs.jpcc.8b12089.

# Major cosmic impact 12,800 years ago

### Geologic and paleontological evidence unearthed in southern Chile supports a major younger Dryas impact event

*ScienceDaily, March 13, 2019*

When UC Santa Barbara geology professor emeritus James Kennett and colleagues set out years ago to examine signs of a major cosmic impact that occurred toward the end of the Pleistocene epoch, little did they know just how far-reaching the projected climatic effect would be.

"It's much more extreme than I ever thought when I started this work," Kennett noted. "The more work that has been done, the more extreme it seems."

He's talking about the Younger Dryas Impact Hypothesis, which postulates that a fragmented comet slammed into the Earth close to 12,800 years ago, causing rapid climatic changes, megafaunal extinctions, sudden human population decrease and cultural shifts and widespread wildfires (biomass burning). The hypothesis suggests a possible triggering mechanism for the abrupt changes in climate at that time, in particular a rapid cooling in the Northern Hemisphere, called the Younger Dryas, amid a general global trend of natural warming and ice sheet melting evidenced by changes in the fossil and sediment record.

Controversial from the time it was proposed, the hypothesis even now continues to be contested by those who prefer to attribute the end-Pleistocene reversal in warming entirely to terrestrial causes. But Kennett and fellow stalwarts of the Younger Dryas Boundary (YDB) Impact Hypothesis, as it is also known, have recently received a major boost: the discovery of a very young, 31-kilometer-wide impact crater beneath the Greenland ice sheet, which they believe may have been one of the many comet fragments that impacted Earth at the onset of the Younger Dryas.

Now, in a paper published in the journal Nature Scientific Reports, Kennett and colleagues, led by Chilean paleontologist Mario Pino, present further evidence of a cosmic impact, this time far south of the equator, that likely lead to biomass burning, climate change and megafaunal extinctions nearly 13,000 years ago.

"We have identified the YDB layer at high latitudes in the Southern Hemisphere at near 41 degrees south, close to the tip of South America," Kennett said. This is a major expansion of the extent of the YDB event." The vast majority of evidence to date, he added, has been found in the Northern Hemisphere.

This discovery began several years ago, according to Kennett, when a group of Chilean scientists studying sediment layers at a well-known Quaternary paleontological and archaeological site, Pilauco Bajo, recognized changes known to be associated with YDB impact event. They included a "black mat" layer, 12,800 years in age, that coincided with the disappearance of South American Pleistocene megafauna fossils, an abrupt shift in regional vegetation and a disappearance of human artifacts.

"Because the sequencing of these events looked like what had already been described in the YDB papers for North America and Western Europe, the group decided to run analyses of impact-related proxies in search of the YDB layer," Kennett said. This yielded the presence of microscopic spherules interpreted to have been formed by melting due to the extremely high temperatures associated with impact. The layer containing these spherules also show peak concentrations of platinum and gold, and native iron particles rarely found in nature.

"Among the most important spherules are those that are chromium-rich," Kennett explained. The Pilauco site spherules contain an unusual level of chromium, an element not found in Northern Hemisphere YDB impact spherules, but in South America. "It turns out that volcanic rocks in the southern Andes can be rich in chromium, and these rocks provided a local source for this chromium," he added. "Thus, the cometary objects must have hit South America as well."

Other evidence, which, Kennett noted, is consistent with previous and ongoing documentation of the region by Chilean scientists, pointed to a "very large environmental disruption at about 40 degrees south." These included a large biomass burning event evidenced by, among other things, micro-charcoal and signs of burning in pollen samples collected at the impact layer. "It's by far the biggest burn event in this region we see in the record that spans thousands of years," Kennett said. Furthermore, he went on, the burning coincides with the timing of major YDB-related burning events in North America and western Europe.

The sedimentary layers at Pilauco contain a valuable record of pollen and seeds that show change in character of regional vegetation -- evidence of a shifting climate. However, in contrast to the Northern Hemisphere, where conditions became colder and wetter at the onset of the Younger Dryas, the opposite occurred in the Southern Hemisphere.

"The plant assemblages indicate that there was an abrupt and major shift in the vegetation from wet, cold conditions at Pilauco to warm, dry conditions," Kennett said. According to him, the atmospheric zonal climatic belts shifted "like a seesaw," with a synergistic mechanism, bringing warming to the Southern Hemisphere even as the Northern Hemisphere experienced cooling and expanding sea ice. The rapidity -- within a few years -- with which the climate shifted is best attributed to impact-related shifts in atmospheric systems, rather than to the slower oceanic processes, Kennett said.

Meanwhile, the impact with its associated major environmental effects, including burning, is thought to have contributed to the extinction of local South American Pleistocene megafauna -- including giant ground sloths, sabretooth cats, mammoths and elephant-like gomphotheres -- as well as the termination of the culture similar to the Clovis culture in the north, he added. The amount of bones, artifacts and megafauna-associated fungi that were relatively abundant in the soil at the Pilauco site declined precipitously at the impact layer, indicating a major local disruption.

The distance of this recently identified YDB site -- about 6,000 kilometers from the closest well-studied site in South America -- and its correlation with the many Northern Hemispheric sites "greatly expands the extent of the YDB impact event," Kennett said. The sedimentary and paleo-vegetative evidence gathered at the Pilauco site is in line with previous, separate studies conducted by Chilean scientists that indicate a widespread burn and sudden major climate shifts in the region at about YDB onset. This new study further bolsters the hypothesis that a cosmic impact triggered the atmospheric and oceanic conditions of the Younger Dryas, he said.

"This is further evidence that the Younger Dryas climatic onset is an extreme global event, with major consequences on the animal life and the human life at the time," Kennett said. "And this Pilauco section is consistent with that."

**Journal Reference**: Mario Pino, Ana M. Abarzúa, Giselle Astorga, Alejandra Martel-Cea, Nathalie Cossio-Montecinos, R. Ximena Navarro, Maria Paz Lira, Rafael Labarca, Malcolm A. LeCompte, Victor Adedeji, Christopher R. Moore, Ted E. Bunch, Charles Mooney, Wendy S. Wolbach, Allen West, James P. Kennett. Sedimentary record from Patagonia, southern Chile supports cosmic-impact triggering of biomass burning, climate change, and megafaunal extinctions at 12.8 ka. *Scientific Reports*, 2019; 9 (1) DOI: 10.1038/s41598-018-38089-y.

## NCGS ANNUAL DINNER MEETING

**Wednesday May 29, 2019**
Orinda Masonic Center, 9 Altarinda Road, Orinda, CA

## *The Beginning of the Plate Tectonics Revolution: Historical Perspective of Experience at Columbia and Scripps Institution of Oceanography*

**Dr. Tanya Atwater**
**Professor Emerita, UC Santa Barbara**

*Reservations are required by May 21, 2019; Limit 100 persons*
*We are sorry, but we will not be able to accommodate "walk-ins"*

**TIME: 6:00 – 6:45 pm, Social 6:45 – 8:00 pm, Dinner 8:00 – 9:00 pm, Presentation**

**COST: $25/person; $15/student. Submit REGISTRATION FORM (below) by May 21.**

The **NCGS** is pleased to host our Annual May Dinner Meeting with **Dr. Atwater**. The dinner, catered by *Back Forty Texas BBQ*, will include Pork Ribs and BBQ Chicken, Tossed Green Salad, BBQ Beans, Potato Salad, Fresh Corn Cobettes, and Ranch Rolls; a Vegetarian Burger is available upon request. NCGS will provide a selection of wine, beer, and non-alcoholic beverages. Contributed desserts will be happily accepted!

The speaker's bio and details of her presentation will be included in our May newsletter.

****************************** **Dinner Logistics** **********************************

**Social Hour:** 6:00 – 6:45 pm **Dinner:** 6:45 – 8:00 pm **Presentation:** 8:00 – 9:00 pm
**Cost:** $25/person; $15/student **Dinner Options:** Regular BBQ or Veg Burger (select below)

******✂*************** **May 2019 Dinner Registration** **************************

Name(s):_______________________________________________________________________

_______________________________________________________________________________

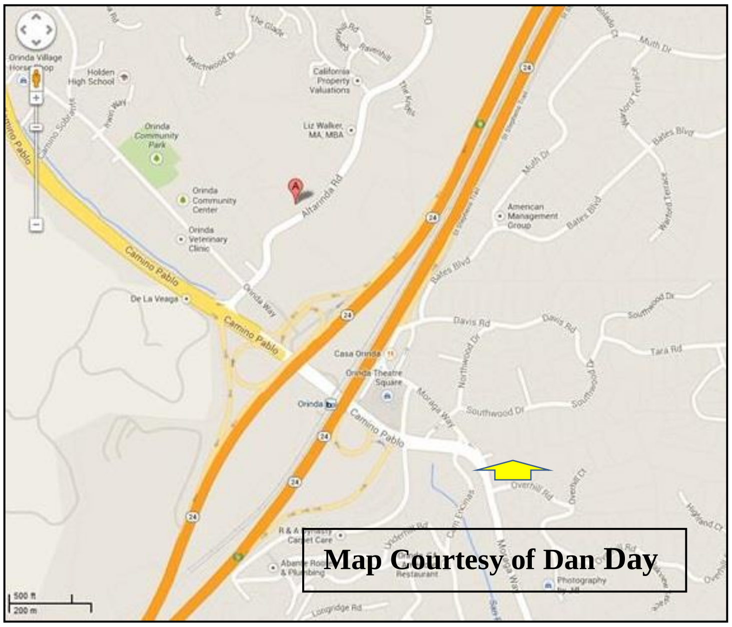
e-mail:_____________________________________ Phone:______________________________________

Number of People attending _________ @ $25 each = Amount Enclosed: $__________________

Number of Students attending ________ @ $15 each = Amount Enclosed: $_________________

Indicate # of people for: Regular BBQ Dinner ________ or Vegetarian Burger ________

Please clip and mail this registration form with a check made out to **NCGS** to:
**Barbara Matz, NCGS Treasurer, 803 Orion #2, Hercules, CA 94547.**
Questions? barbmatz@yahoo.com or 415-713-8482 (cell)



Map Courtesy of Dan Day

***(Continued from Page 1)***

California. We will discuss how these ages can help reconstruct the depositional ages of these units and place constraints on their origin.

***Biography:*** Owen Anfinson completed a B.A. in geology from the University of Minnesota, followed by an M.S. from Washington State University, and a Ph.D. from the University of Calgary in 2012. He was also a distinguished postdoctoral fellow at the Jackson School of Geoscience at The University of Texas at Austin from 2012 to 2015. He is primarily a tectonic sedimentologist, meaning that most of my research focuses on utilizing tools such as detrital geochronology and thermochronology to understand tectonic problems. My research has spanned a wide range of field areas from the Channeled Scablands of Washington to the Canadian and Russian Arctic.

Locally, his current research focuses on sedimentologic and tectonic problems associated with strata of the Franciscan Complex and the Sur Series. Globally, he still remains closely tied to Arctic Tectonics and has a small number of active projects in the Swiss and Italian Alps.

Northern California Geological Society
c/o Mark Sorensen
734 14th Street, #2
San Francisco, CA 94114

***Would you like to receive the NCGS newsletter by e-mail?*** If you are not already doing so, and would like to, please contact Tom Barry at **tomasbarry@aol.com** to sign up for this free service.