NORTHERN CALIFORNIA GEOLOGICAL SOCIETY

MEETING ANNOUNCEMENT

DATE: **Wednesday, October 30, 2019**

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

TIME: **Social Hour: 6:30 – 7 pm; Program: 7 pm**

SPEAKER: ***Dr. Russell Graymer, USGS***

TOPIC: ***"Geologic and geophysical framework of Mt Diablo"***

Based on the upcoming article "Structural and seismic hazard implications of geologic map and potential field geophysical observations at Mount Diablo, California"

Mount Diablo has been characterized as a large overturned anticline, but its actual structure is more complex. Offset geologic units and gravity/magnetic anomalies show the mountain is bisected by the reverse-oblique right-lateral Greenville-Diablo-Concord fault zone (GDCFZ) with 15-20 km of Pliocene and younger strike-slip offset. Thus the mountain is formed of two structural blocks with different stratigraphy and structural style. The western block is characterized by a thin (<1 km) Paleogene section and thick (>4 km) Neogene section, with a broad active fold and thrust belt formed in response both to a restraining bend in the GDCFZ and to regional fault-normal compression. The uplifted eastern block is characterized by a locally thick (~3 km) Paleogene section and a thin (<1 km) exposed Neogene section, with a Paleogene normal fault system forming a stepped graben tilted up by Neogene compression. The Neogene compression has also formed roughly fault-parallel folds, including the Mt Diablo anticline on the uplifted eastern block near the GDCFZ. At the peak of Mt Diablo, intense deformation in the restraining stepover has distorted the fold axes and maximized basement uplift, so that the basement rocks of the Franciscan Complex and Coast Range ophiolite are only exposed at the highest parts of the mountain. The elongate gravity high associated with the Mt Diablo anticline is offset 2-3 km to the east of the fold axis, reflecting either a fault detachment between the basement and overlying strata or the pre-folding basement geometry. Lack of appreciable offset on the gravity high precludes significant strike-slip offset on faults directly east of Mt Diablo. Some earlier **(continued on last page)**

NCGS 2019 – 2020 Calendar

November 20 **7:00 pm**

(1 week early because of Thanksgiving)

Dr. Dr. David P. Schwartz, USGS

Earthquakes in the East Bay

January 29 **7:00 pm**

Program not yet set

February 26 and later dates through June **7:00 pm**

Programs not yet set

THE 75th ANNIVERSARY VOLUME OF THE NORTHERN CALIFORNIA GEOLOGICAL SOCIETY:

THE REGIONAL GEOLOGICAL SETTING OF MOUNT DIABLO

The following table summarizes the contributions to the Volume scheduled to be published by the Geological Society of America in December 2020.

The editors are Ray Sullivan, Doris Sloan, Jeff Unruh and David Schwartz.

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NCGS 75th Anniversary

It's 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 progressing toward completion of the release ***The Regional Geologic Setting of Mount Diablo*** in a special publication of the GSA. This fall, we plan to run several **field trips** on and near the mountain, and will keep you posted. 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!

NCGS Field Trip

"A Fresh Look at the Geology of Mount Diablo's Summit and Southwest Flank"

Saturday, November 2, 2019 starting at 9:30 am

Leaders: Dr. Will Schweller and Dr. Don Medwedeff

This half-day field trip will give participants an updated understanding of the geology of Mount Diablo, focusing on the Franciscan Complex that forms the upper half of the mountain and the Cretaceous and Tertiary sedimentary formations that form the southwest flank of the mountain, plus the structural and tectonic processes that created this mountain.

The trip will begin near the top of the mountain, at the large parking area just below the summit, and proceed

downhill to end at Rock City, just before the ranger station at the park's south entrance. Please see details in the form emailed recently by Crystal Replogle, and mail in your reservation. Don't dally! However, the good news is that Will and Don will likely run another trip!

NCGS Outreach Opportunity: Bay Area Science Festival

On Oct. 26th will be at Cal. State East Bay for the Bay Area Science Festival (BASF). Our planned participation in BASF at AT&T Park (Giants' stadium) has been cancelled due to a dearth of participants. If anyone wants to take the lead on participation at the AGU convention in December, please do so and let me know. Mark Petrofsky mpetrof@hotmail.com!

Pacific Section SEPM Fall Field Trip

Lisa Alpert, PS-SEPM President, says that this year, the field trip will be to the Inyo Mountains on October 27-29th. Please see visit their webpage for more information and registration, at

https://www.pacificsectionsepm.org/2019-field-trip

You will need to have an updated membership to attend the field trip. See their website for membership information or to update your information:

https://www.pacificsectionsepm.org/membership

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 on Thursdays (usually) at 3:45 pm for most of the academic year, from late August through early May. On October 24, Jon Husson of University of Victoria will speak on ***GeoDeepDive: a digital library and cyberinfrastructure for Earth System Science in the age of 'Big Data'*** *(Joint with the EPS library).* For a list of seminars, go to http://eps.berkeley.edu/events/seminars.

NCGS members are invited our next **Board of Directors meeting,** in January at the APTIM office at 4005 Port Chicago Highway. Board meetings will now be generally held at 9 am on a Saturday in January, May, and September, and are open to all NCGS members. Please contact Tom MacKinnon if you'd like to attend, at tom.mackinnon@comcast.net.

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, ***November 21st*** at 7 pm by ***Sean Vitousek***, USGS, on ***Sea-Level Rise, Extreme Water Levels, and Coastal Erosion... How bad could it possibly be?*** at Rambo Auditorium, 345 Middlefield Road, Menlo Park. For more information on the lectures, and for a map of the location, go to: https://online.wr.usgs.gov/calendar/.

Welcome back from summer break! And that means it's time to renew your membership!

We realize that it's still summer – especially in California – but September is when our program year begins. Please 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.

Help Requested at Math Science Nucleus

Joyce Blueford at MS Nucleus says that they are redoing their rock and mineral hall. They have 2 display cases that she wants to place the mineral specimens by their chemical families. They have many specimens (not always the best), but are looking for someone who might want to put a display together. Minerals are easy because everyone likes to look at pretty shapes....

They do have a rock display that the kids use in their scavenger hunt, but most of the rock education is done in field trips. However, they are always interested in making rocks tell a story.... they like to change displays, but would welcome any help.

Mark Petrofsky and Paul Henshaw are coordinating this with Joyce, and they suggest that this could be an ongoing project with periodic changes to the display, annually or biannually. Joyce also wants to make the geology portion of the museum more interactive. We could also go beyond the display cases to maps and materials on local geology and display books about

local geology. NCGS has provided the California geologic maps, large and 8x10, for MSNucleus use with teachers and students. A continuing and expanding long term relationship would be great.

Astronomy and evolution

Human beings may owe their existence to nearby supernovas

Cosmic rays from them would have changed the world's vegetation

The Economist, May 30, 2019

If a supernova went off near Earth, that would be bad. From a distance of less than, say, 25 light-years, the resulting bombardment of fast-moving atomic nuclei, known as cosmic rays, would destroy the layer of atmospheric ozone that stops most of the sun's harmful ultraviolet light reaching Earth's surface. In combination, these two kinds of radiation, cosmic and ultraviolet, would then kill many forms of life.

If a supernova went off not quite so close by, though, that might be interesting. It would have effects, but more subtle ones. Indeed, a paper published in the latest edition of the Journal of Geology, by Brian Thomas of Washburn University, in Kansas, and Adrian Melott of the University of Kansas, suggests that a series of such stellar explosions may have nudged humanity's forebears down from their trees and up onto their hind legs.

The chain of events Dr. Thomas and Dr. Melott propose starts with the observation that between 14 and 20 supernovas have gone off in Earth's vicinity over the past 8 million years. These explosions, of young, massive stars, are believed to have happened in the Tucana-Horologium stellar group, currently about 130 light-years from Earth.

One reasn for believeing these supernovas occurred is that the shock waves from them swept away nearby interstellar gas and the magnetic field which threads through that gas. This has left the sun embedded in what is known as the Local Bubble, a peanut-shaped void 300 light-years long in which the vacuum of space is even emptier than normal, and which is bounded by a wall of somewhat denser gas and stronger magnetic fields.

Once the Local Bubble was established, any cosmic rays created by a supernova within it would have kept bouncing off this magnetic wall and back into the bubble. They would this have strafed every object within it, including Earth, for tens, or even hundreds of thousands of years after the explosions that created them.

Some of these rays were the nuclei of a radioactive isotope of iron that is created almost exclusivelt in supernovas. These unstable nuclei, together with their decay products, have been found in the ocean floor on Earth and in rock samples brought from the Moon – another reason to believe the supernovas happened. Those isotopes found on Earth can be dated from the sediment they are in. The strongest signal is from 2.5 My ago, indicating that this explosion was the closest.

A geological feature that coincides with the period when Local Bubble supernovas were going off is an increase in traces of charcoal in oceanic sediments. That is evidence of wildfires on land. This increase starts about 7 My ago, and in turn coincides with a period when much of Earth's vegetation shofted from forests to grasslands. The fires recorded by the oceanic charcoal could explain this vegetational shift, because grass is more resilient to fire than trees are. What explains the fires, though, remains mysterious.

Drs. Thomas and Melott propose that the cuplrit is cosmic rays from the local supernovas. The main arsonist of wildfires is lightning. The hammering of atmospheric molecules these rays handed out, they suggest, caused more lightning. The rays would knock such molecules apart, liberating electrons from their atoms. These liberated electrons would in turn knock loose other electrons, creating cascades that would make the air electrically conductive. This would encourange lightning strikes.

Observation made recently on a mountainside in Armeia, of electron cascades caused by normal cosmic rays, showed that many of these did indeed end in a lightning flash, so the idea is plausible. Encouraged by this, Drs. Thomas and Melott calculated the effect that the cosmic rays of the explosion of 2.5 My agowould have had on the number of cascades. They conclude that the cascade rate would have increased 50-fold.

The replacement of forest by grassland is though by some anthropolists to have encouraged the evolution of humanity's ancestors away from tree-dwelling and towards bipedalism. It was this change in locomotion that freed human hands to get up to all the mischief which distinguishes people from other species. Human beings,

in all their manipulative glory, are thus, if the chain of events Drs. Thomas and Melott are suggesting is correct, the children of dying stars.

Human evolution

Did cooking in hot springs make humans brainy?

Geothermal springs could help explain how early humans evolved such big brains

The Economist, May 25, 2019

How and why, roughly 2m years ago, early human ancestors evolved large brains and began fashioning relatively advanced stone tools, is one of the great mysteries of evolution. Some researchers argue these changes were brought about by the invention of cooking. They point out that our bite weakened around the same time as our larger brains evolved, and that it takes less energy to extract nutrients from cooked food. As a result, once they had mastered the art, early chefs could pare back their digestive systems and invest the resulting energy savings in building larger brains capable of complex thought. There is, however, a problem with the cooking hypothesis. Most archaeologists believe the evidence of controlled fire stretches back no more than 790,000 years.

Roger Summons of the Massachusetts Institute of Technology has a solution. Together with his team of geomicrobiologists, he analysed 1.7m-year-old sandstones that formed in an ancient river at Olduvai Gorge in Tanzania. The region is famous for the large number of human fossils that have been discovered there, alongside an impressive assembly of stone tools. The sandstones themselves have previously yielded some of the world's earliest sophisticated Acheulean hand axes: large teardrop-shaped stone tools that are associated with *Homo erectus*. Creating an Acheulean axe by repeatedly knocking flakes off of a raw stone in order to create two sharp cutting edges requires a significant amount of planning. Their appearance is therefore thought to mark an important moment in cognitive evolution.

Trapped inside the Olduvai sandstones, the researchers found distinctive but unusual biological molecules that are often interpreted as biomarkers for heat-tolerant bacteria. Some of these thrive in water between 85 and 95 ºC. The molecules' presence suggests that an ancient river within the gorge was once fed by one or more hot springs, fitting niceky with its location within the geologically active East African Rift. The findings are published in a paper posted to the only ***bioRxiv*** preprint server.

Dr. Summons and his colleagues say the hot springs would have provided a convenient "pre-fire" means of cooking food. In Rotorua in New Zealand, the Maori have traditionally cooked food in geothermal springs (see photo), either by lowering it into the boiling water or by digging a hole in the hot earth. Similar method exist in Japan and Iceland, so it is plausible, if difficult to prove, that early humans might have used hot springs to simmer meat and roots.

Richard Wrangham, a primatologist at Harvard University who devised the cooking hypothesis, is intrigued by the idea. Nonetheless, fire would have offered a distinct advantage humans, once they had mastered the art of controlling it since, unlike a hot spring, it is a portable resource.

Livermore Oil Sees 150th Anniversary

AAPG Explorer, Historical Highlights, September 2019

by Alan K. Burnham

When asked what they know about Livermore, Calif., most people think of the nuclear weapons laboratory with the largest lasers and computers, and some think of the oldest wine region in the state, but no one thinks of it as an oil producing region. Yet Livermore was the site of one of the earliest oil wells in California and still has a small, declining oil field just east of Lawrence Livermore National Laboratory. In fact, 2019 is the 150th anniversary not only of the periodic chart and the first transcontinental

railroad (which went through Livermore), but also the first oil well drilled near Livermore.

The first well was drilled in the spring of 1869 at the site of an explosion and oil seep caused by the 1868 earthquake on the Hayward Fault, which damaged buildings throughout the San Francisco Bay Area, killed 30 people, and was felt as far away as Nevada. This 10-feet deep well, just past the northeast edge of the current city limit, produced about five gallons of heavy oil per hour for a while, but was not sustained. Several more wells up to 200-feet deep were drilled in the area over the next 20 years, which produced oil shows, but no commercially viable production. Even now, rainwater in the street gutters in that area occasionally has an oil film.

This inauspicious beginning of Livermore oil exploration has an interesting connection to the 1960s television show "The Beverly Hillbillies." Besides the obvious connection to a specific event causing an oil seep and subsequent drilling, Max Baer, Jr, who played Jethro on that show, is linked to Livermore. His father, Max Baer, Sr., grew up on a pig farm on the south side of town and went on to become a heavyweight boxing champion. Both father and son have ridden in the Livermore Rodeo parade, and Max Baer Park is the current site of the World Series of the Little League Intermediate Division. In addition, an earlier lightweight boxing champion, Battling Nelson, trained south of Livermore and was an investor in oil wells drilled in the 1900s.

Promise and Disappointment

In the early 1900s, Livermore had a population of about 2,000 people, and city leaders thought that oil discoveries would make the town larger and prosperous, like Coalinga, Venture, Bakersfiled, and Los Angeles. California had grown to be the largest oil producer in the country during that era, Spindletop notwithstanding, In fact, the Lakeview gusher near Bakersfield in 1910 was twice as large as Spindletop.

A dozen or so wells were drilled near oil seeps eight miles east of Livermore between 1885 and 1925, with promising but ultimately disappointing results. [Four then-and-now photo pairs are shown in the article.] The Alisal ("Darling") and Independence wells were asource of great hope but ultimate disappointment. The Alisal well was the largest producer at 5 barrels per day – enough to run two drilling rigs. This early activity was near outcrops of the Cierbo Formation, which contains the 2-million-barrel Livermore oil field discovered decased later.

A steel tank from the era remains and is currently used yo collect water for cattle. Diesel fuel to run the drill rigs was pulled up into the Altamont Hills on muddy roads in such tanks by a steam tractor. The writing still visible on the end of the tank identifies it with the Associated Oil Company. Associated Oil was incorporated in San Franciscon in 1901 to bring oil products from Bakersfield and built the Avon refinery (now owned and operated by Marathon Oil after its merger with Andeaver, formerly Tesoro).

After nearly 100 years and 80 non-productive wells, producible oil was finally discovered in January 1967 by McCulloch Oil Corporation between the previous two hotbeds of exploration at the intersection of the Greenville and Las Positas faults. The pay zone is the Greenville Sands in the Miocene Cierbo Formation, which outcrop in the Altamont Hills and are the source of the widespread oil seeps. By isotopic anlaysis, the oil was sourced from an Eocene source rock contemporary to the Kreyenhaugen and Nortonville shales, mostlikely under Dublin and San Ramon a few million years ago after the rise of Mount Diablo. In its 50 years, the field has produced about 80 percent of its estimated 2 million barrels and is currently owned and operated by E&B Resources.

Permitting Struggle

Even though it produces only 0.5% of Livermore's oil consumption and is unknown to most Livermore residents, this field has become the center of a substantial political battle over the past couple years. As it went through renewal of a revised Environmental Protection Agency aquifer exemption permit and the Alameda County conditional use permits, many speakers who opposed these permits clearly did not understand the meaning of the technical words they used, including confusing "oil drilling" with "oil production." Even though no aquifer contamination related to oil-field operations has been detected, operations were portrayed as a threat to local drinking water supplies. Ironically, the neighboring Lawrence Livermore National Laboratory is an EPA Superfund site, cleaning up both chlorinated solvent and gasoline leaks from both its operation and prior operations as a naval air base during World War II.

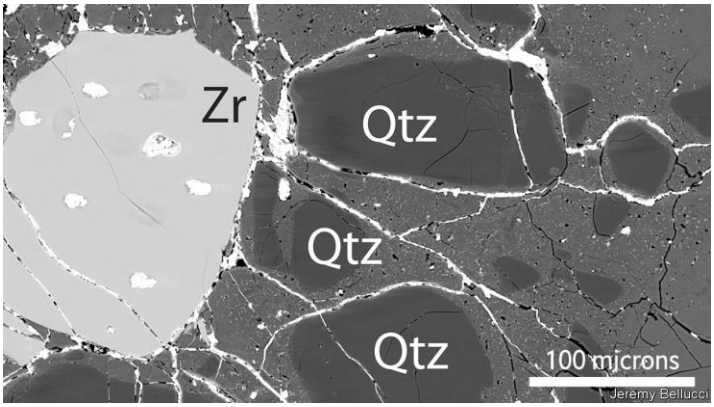
The story of this field continues to unfold. The EPA approved the revised aquifer exemption permit. The Alameda County supervisors voted to overturn the county zoning board extension of conditional use permits, and E&B Resources has filed suit in federal court challenging that decision.

Astrogeology

A rock from the Moon has a tiny piece of Earth inside it

It arrived there 4 billion years ago

The Economist, February 2, 2019



This is a cross-section through a grain from a well-travelled rock. It was brought to Earth from the Fra Mauro highlands of the Moon in 1971, by the crew of Apollo 14. Four billion years before that, though, it had made the journey in the opposite direction, according to an analysis by **Jeremy Bellucci** of the Swedish Museum of Natural History, published in ***Earth and Planetary Science Letters***.

Fra Mauro is composed of ejecta from a celestial collision between an asteroid and the Moon, which excavated the biggest lunar impact basin, Mare Imbrium. Most of the samples returned by Apollo 14 are breccias created by this impact. Breccia is a type of rock formed by the higgledy-piggledy mixing of bits of other rock, and this two-gram grain was part of one such brecciated boulder.

Dr. Bellucci's analysis of the minerals in the grain, particularly its zircon (Zr, in photo) and quartz (Qtx), shows that theu woyuld have been unlikely to form in lunar conditions, but would easily have formed on Earth. The simplest explanation, therefore, is that Earth is where they came from.

Amost certainly, the grain arrived on the Moon as part of a larger rock blasted off Earth's surface by an impact similar to that which created Mare Imbrium. All this happened during a period of the solar system's history called the late heavy bombardment, which lasted from 4.1 to 3.8 billion years ago. The Moon then being only a third as far away from Earth as it is now, travelling to the one from the other would have been an easy journey. The grain was then shifted again, by the Imbrium impact, to form part of the geological splatter now called Fra Mauro.

Terrestrial material this old is rae, so finding some on the Moon has been a useful addition to geologists' collections. And this particular grain may not be unique. Apollo 14 brought back 42 kg of rock. Other chips of the block of old Earth are probably hiding among them.

Faults' hot streaks and slumps could change earthquake hazard assessments

ScienceDaily, September 23, 2019

For more than a century, a guiding principle in seismology has been that earthquakes recur at semi-regular intervals according to a "seismic cycle." In this model, strain that gradually accumulates along a locked fault is completely released in a large earthquake. Recently, however, seismologists have realized that earthquakes often occur in clusters separated by gaps, and one research group now argues that the probability of a tremor's recurrence depends upon whether a cluster is ongoing -- or over.

On Monday, 23 Sept. 2019, at the ***GSA Annual Meeting in Phoenix***, **Seth Stein**, the Deering Professor of Geological Sciences at Northwestern University, presented a new model that he and his co-authors believe better explains the complexity of the "supercycles" that have been observed in long-term earthquake records. "One way to think about this is that faults have hot streaks -- earthquake clusters -- as well as slumps -- earthquake gaps -- just like sports teams," says Stein.

In the traditional concept of the seismic cycle, Stein explains, the likelihood of a large earthquake depends solely upon the amount of time that has elapsed since the most recent large tremor reset the system. In this simple case, he says, the fault has only a "short-term memory."

"The only thing that matters," says Stein, "is when the last big earthquake was. The clock is reset every time there's a big event."

But this model is not realistic, he argues. "We would never predict the performance of a sports team based on how they performed during their previous game," says Stein. "The rest of the season is likely to be much more useful."

Geologists sometimes see long-term patterns in paleoseismic records that the seismic-cycle model can't explain. In these cases, says Stein, "Not all the accumulated strain has been released after one big earthquake, so these systems have what we call "long-term memories.'"

To get a sense of how a system with Long-Term Fault Memory would function, the researchers sampled windows of 1,300-years -- a period of time for which geologists might reasonably have a record available -- from simulated 50,000-year paleoseismic records. The results indicate that earthquake recurrence intervals

looked very different depending upon which 1,300-year window the scientists examined.

Because there are random elements involved, says Stein, there are windows when the recurrence intervals appear to be periodic, and other times when they look clustered. "But the fault hasn't changed its properties," he says. Eventually, the model predicts that the earthquakes will release much of the accumulated strain, at which point the system will reset and the fault's "streak" will end.

According to this Long-Term Fault Memory model, the probability of an earthquake's occurrence is controlled by the strain stored on the fault. This depends on two parameters: the rate at which strain accumulates along the fault, and how much strain is released after each big earthquake. "The usual earthquake-cycle model assumes that only the last quake matters," says Stein, "whereas in the new model, earlier quakes have an effect, and this history influences the probability of an earthquake in the future." After a big quake, he says, there can still be lots of strain left, so the fault will be on a hot streak. Eventually, however, most of the strain is released and the fault goes into a slump.

Ultimately, says Stein, the earthquake hazard depends upon whether or not a fault is in a slump or a streak. "Depending on which of those assumptions you make," he says, "you can get the earthquake probability much higher or much lower."

Seismologists have not yet come up with a compelling way to determine whether a fault is -- or is not -- in a cluster. As a result, says Stein, "There's a much larger uncertainty in estimates of the probability of an earthquake than people have been wanting to admit."

Story Source: Presentation by Seth Stein at Geological Society of America Annual Meeting, Sept. 23. 2019: "Faults' hot streaks and slumps could change earthquake hazard assessments."

Machu Picchu: Ancient Incan sanctuary intentionally built on faults

ScienceDaily, September 23, 2019

Machu Picchu, Peru (stock image).

Credit: © amadeustx / Adobe Stock

The ancient Incan sanctuary of Machu Picchu is considered one of humanity's greatest architectural achievements. Built in a remote Andean setting atop a narrow ridge high above a precipitous river canyon, the site is renowned for its perfect integration with the spectacular landscape. But the sanctuary's location has long puzzled scientists: Why did the Incas build their masterpiece in such an inaccessible place? Research suggests the answer may be related to the geological faults that lie beneath the site.

On Monday, 23 Sept. 2019, at the ***GSA Annual meeting in Phoenix***, **Rualdo Menegat**, a geologist at Brazil's Federal University of Rio Grande do Sul, will present the results of a detailed geoarchaeological analysis that suggests the Incas intentionally built Machu Picchu -- as well as some of their cities -- in locations where tectonic faults meet. "Machu Pichu's location is not a coincidence," says Menegat. "It would be impossible to build such a site in the high mountains if the substrate was not fractured."

Using a combination of satellite imagery and field measurements, Menegat mapped a dense web of intersecting fractures and faults beneath the UNESCO World Heritage Site. His analysis indicates these features vary widely in scale, from tiny fractures visible in individual stones to major, 175-kilometer-long lineaments that control the orientation of some of the region's river valleys.

Menegat found that these faults and fractures occur in several sets, some of which correspond to the major fault zones responsible for uplifting the Central Andes Mountains during the past eight million years. Because some of these faults are oriented northeast-southwest and

others trend northwest-southeast, they collectively create an "X" shape where they intersect beneath Machu Picchu.

Menegat's mapping suggests that the sanctuary's urban sectors and the surrounding agricultural fields, as well as individual buildings and stairs, are all oriented along the trends of these major faults. "The layout clearly reflects the fracture matrix underlying the site," says Menegat. Other ancient Incan cities, including Ollantaytambo, Pisac, and Cusco, are also located at the intersection of faults, says Menegat. "Each is precisely the expression of the main directions of the site's geological faults."

Menegat's results indicate the underlying fault-and-fracture network is as integral to Machu Picchu's construction as its legendary stonework. This mortar-free masonry features stones so perfectly fitted together that it's impossible to slide a credit card between them. As master stoneworkers, the Incas took advantage of the abundant building materials in the fault zone, says Menegat. "The intense fracturing there predisposed the rocks to breaking along these same planes of weakness, which greatly reduced the energy needed to carve them."

In addition to helping shape individual stones, the fault network at Machu Picchu likely offered the Incas other advantages, according to Menegat. Chief among these was a ready source of water. "The area's tectonic faults channeled meltwater and rainwater straight to the site," he says. Construction of the sanctuary in such a high perch also had the benefit of isolating the site from avalanches and landslides, all-too-common hazards in this alpine environment, Menegat explains.

The faults and fractures underlying Machu Picchu also helped drain the site during the intense rainstorms prevalent in the region. "About two-thirds of the effort to build the sanctuary involved constructing subsurface drainages," says Menegat. "The preexisting fractures aided this process and help account for its remarkable preservation," he says. "Machu Picchu clearly shows us that the Incan civilization was an empire of fractured rocks."

Story Source: Geological Society of America: Presentation by Rualdo Menegat at the GSA Annual meeting in Phoenix, Monday, 23 Sept. 2019.

Promoting earth's legacy delivers local economic benefits

ScienceDaily, September 23, 2019

For iconic landscapes such as Grand Canyon or the Appalachian Mountains, geological features are an integral part of their appeal. Yet despite the seeming permanence of cliffs, caves, fossils, and other geological highlights, these features are surprisingly vulnerable to damage or destruction. Across the U.S., there is a growing awareness that America's geological resources represent a common heritage that needs to be preserved -- and that doing so can yield considerable economic and societal benefits.

The notion of a shared geological record is central to the concept of geoheritage: the idea that people, landscapes, and the processes that have formed -- and continue to shape -- our planet are interconnected. Ways to protect and promote America's geoheritage, and the benefits of doing so, was the focus of two sessions of talks presented at ***GSA's Annual Meeting in Phoenix***.

"The only evidence of Earth's long history is the rock record. This can vary dramatically from place to place, so it's crucial to conserve this legacy," says Tom Casadevall, scientist emeritus at the U.S. Geological Survey and chair of the National Academy of Sciences-sponsored U.S. Geoheritage and Geoparks advisory group. "Geoheritage sites are crucial for advancing scientific and public knowledge about important topics like natural hazards, the evolution of life, and our nation's energy and mineral supplies."

In the U.S., sites of geological significance are protected at a variety of management levels and administered by numerous federal land-management agencies, including the National Park Service, the Bureau of Land Management, and the U.S. Forest Service, as well as state, tribal, and local entities. "During the last decade, there has been more and more interest in developing geoheritage sites," says Casadevall. "I have seen first-hand the economic, educational, and social benefits that can be derived from geology-related tourism, and I believe more American communities could benefit from this approach."

State geological surveys are playing a lead role in developing and promoting geology-related sites and educational programs across the country, according to Casadevall. In Florida, the state geologist has the authority to designate state geologic sites deemed important for scientific study as well as public understanding of the state's geological history. Four such sites have been designated to date.

In the central Appalachians, West Virginia University, the West Virginia Geological and Economic Survey, and the U.S. Geological Survey have developed an Appalachian Geo-STEM camp where high school students can engage in geoscience through outdoor adventure education activities. The university is also working with three southern counties to create an Appalachian Geopark that showcases the region's coal, caves, rivers, and other natural attributes and how these underpin the local culture.

Many state surveys also distribute educational materials, develop geo-tours, post blogs, and help catalog geosite attributes to guide tourism development. "State geological surveys play a vital role in translating the geological origins of interesting features into terms that non-scientists can understand," says Nelia Dunbar, New Mexico's state geologist.

In Texas, the Bureau of Economic Geology has begun several educational initiatives, including the Texas GeoSign Project, to promote geoheritage in the Lone Star State. The Arizona Geological Survey is currently cataloging more than 1,500 unpublished geologic and mining documents related to the Santa Cruz Valley National Heritage Area, which was established earlier this year. And the New Mexico Bureau of Geology & Mineral Resources is developing "e-materials" to help curious visitors understand the stories behind state's beautiful scenery and the valuable resources like turquoise that are so closely intertwined with New Mexico's rich cultural history.

"Growing awareness of the power of the 'geoheritage' approach has provided us with a pathway to increase awareness of the links between geology and human history," says Dunbar. "We look forward to increasing our reach and relevance through this new direction."

Story Source: Presentations at the Geological Society of America annual meeting in Phoenix. "Promoting earth's legacy delivers local economic benefits." ScienceDaily. ScienceDaily, 23 September 2019.

Humankind did not live with a high-carbon dioxide atmosphere until 1965

ScienceDaily, September 25, 2019
Source: Texas A&M University

Humans have never before lived with the high carbon dioxide atmospheric conditions that have become the norm on Earth in the last 60 years, according to a new study that includes a Texas A&M University researcher.

Titled "Low CO2 levels of the entire Pleistocene Epoch" and published in Nature Communications today, the study shows that for the entire 2.5 million years of the Pleistocene era, carbon dioxide concentrations averaged 250 parts per million. Today's levels, by comparison, are more than 410 parts per million. In 1965, Earth's carbon dioxide atmospheric concentrations exceeded 320 parts per million, a high point never reached in the past 2.5 million years, the study shows.

"According to this research, from the first Homo erectus, which is currently dated to 2.1 to1.8 million years ago, until 1965, we have lived in a low-carbon dioxide environment -- concentrations were less than 320 parts per million," said Yige Zhang, a co-author of the research study and an assistant professor in the Department of Oceanography in the College of Geosciences. "So this current high-carbon dioxide environment is not only an experiment for the climate and the environment -- it's also an experiment for us, for ourselves."

Carbon dioxide is a greenhouse gas that contributes to the warming of Earth's atmosphere, and is considered a driver of global climate change, Zhang said.

"It's important to study atmospheric CO2 (carbon dioxide) concentrations in the geological past, because we know that there are already climate consequences and are going to be more climate consequences, and one way to learn about those consequences is to look into Earth's history," Zhang said. "Then we can see what kind of CO2 levels did we have, what did the climate look like, and what was the relationship between them."

Jiawei Da, Xianqiang Meng and Junfeng Ji, all of Nanjing University in China, and Gen Li of the California Institute of Technology co-authored the research.

The scientists analyzed soil carbonates from the Loess Plateau in central China to quantify ancient atmospheric carbon dioxide levels as far back as 2.5 million years ago. Climate scientists often use ice cores as the "gold standard" in physical climate records, Zhang said, but ice cores only cover the past 800,000 years.

Analyzing Paleogenic carbonates found in the ancient soil, or paleosols, from the Loess Plateau, the scientists reconstructed the Earth's carbon dioxide levels.

"The Loess Plateau is an incredible place to look at aeolian, or wind, accumulation of dust and soil," Zhang said. "The earliest identified dust on that plateau is from 22 million years ago. So, it has extremely long records. The layers of loess and paleosol there contain soil carbonates that record atmospheric carbon dioxide, if we have very careful eyes to look at them."

"Specifically, carbonates formed during soil formation generally reach carbon isotopic equilibrium with ambient soil CO2, which is a mixture of atmospheric CO2 and CO2 produced by soil respiration," said Nanjing University's Jiawei Da. "Through the application of a two-component mixing model, we can reconstruct paleo-CO2 levels using carbonates in fossil soils."

Using those materials and the techniques, the researchers constructed a carbon dioxide history of the Pleistocene.

"Our reconstructions show that for the entire Pleistocene period, carbon dioxide averaged around 250 parts per million, which is the same as the last 800,000 years' values," Zhang said.

"Our paleosol-based CO2 estimates are in line with snapshots of early-Pleistocene CO2 retrieved from Antarctic old, blue ice, suggesting that the Earth system has been operating under low CO2 levels throughout the Pleistocene," said Junfeng Ji of Nanjing University.

We evolved in a low-carbon-dioxide environment, Zhang said, and how humans will evolve and be affected by today's carbon-dioxide levels is yet to be seen.

Journal Reference: Jiawei Da, Yi Ge Zhang, Gen Li, Xianqiang Meng, Junfeng Ji. Low CO2 levels of the entire Pleistocene epoch. *Nature Communications*, 2019; 10 (1) DOI: 10.1038/s41467-019-12357-5.

Dust from a giant asteroid crash caused an ancient ice age

ScienceDaily, September 18, 2019
Source: Field Museum of Natural History

About 466 million years ago, long before the age of the dinosaurs, the Earth froze. The seas began to ice over at the Earth's poles, and the new range of temperatures around the planet set the stage for a boom of new species evolving. The cause of this ice age was a mystery, until now: a new study in Science Advances argues that the ice age was caused by global cooling, triggered by extra dust in the atmosphere from a giant asteroid collision in outer space.

There's always a lot of dust from outer space floating down to Earth, little bits of asteroids and comets, but this dust is normally only a tiny fraction of the other dust in our atmosphere such as volcanic ash, dust from deserts and sea salt. But when a 93-mile-wide asteroid between Mars and Jupiter broke apart 466 million years ago, it created way more dust than usual. "Normally, Earth gains about 40,000 tons of extraterrestrial material every year," says Philipp Heck, a curator at the Field Museum, associate professor at the University of Chicago, and one of the paper's authors. "Imagine multiplying that by a factor of a thousand or ten thousand." To contextualize that, in a typical year, one thousand semi trucks' worth of interplanetary dust fall to Earth. In the couple million years following the collision, it'd be more like ten million semis.

"Our hypothesis is that the large amounts of extraterrestrial dust over a timeframe of at least two million years played an important role in changing the climate on Earth, contributing to cooling," says Heck.

"Our results show for the first time that such dust, at times, has cooled Earth dramatically," says Birger Schmitz of Sweden's Lund University, the study's lead author and a research associate at the Field Museum. "Our studies can give a more detailed, empirical-based understanding of how this works, and this in turn can be used to evaluate if model simulations are realistic."

To figure it out, researchers looked for traces of space dust in 466-million-year-old rocks, and compared it to tiny micrometeorites from Antarctica as a reference. "We studied extraterrestrial matter, meteorites and micrometeorites, in the sedimentary record of Earth, meaning rocks that were once sea floor," says Heck. "And then we extracted the extraterrestrial matter to discover what it was and where it came from."

Extracting the extraterrestrial matter -- the tiny meteorites and bits of dust from outer space -- involves taking the ancient rock and treating it with acid that eats away the stone and leaves the space stuff. The team then analyzed the chemical makeup of the remaining dust. The team also analyzed rocks from the ancient seafloor and looked for elements that rarely appear in Earth rocks and for isotopes -- different forms of atoms -- that show hallmarks of coming from outer space. For instance, helium atoms normally have two protons, two neutrons, and two electrons, but some that are shot out of the Sun and into space are missing a neutron. The presence of these special helium isotopes, along with rare metals often found in asteroids, proves that the dust originated from space.

Other scientists had already established that our planet was undergoing an ice age around this time. The amount of water in the Earth's oceans influences the way that rocks on the seabed form, and the rocks from this time period show signs of shallower oceans -- a hint that some of the Earth's water was trapped in glaciers and sea ice. Schmitz and his colleagues are the first to show that this ice age syncs up with the extra dust in the atmosphere. "The timing appears to be perfect," he says. The extra dust in the atmosphere helps explain the ice age -- by filtering out sunlight, the dust would have caused global cooling.

Since the dust floated down to Earth over at least two million years, the cooling was gradual enough for life to adapt and even benefit from the changes. An explosion of new species evolved as creatures adapted for survival in regions with different temperatures.

Heck notes that while this period of global cooling proved beneficial to life on Earth, fast-paced climate change can be catastrophic. "In the global cooling we studied, we're talking about timescales of millions of years. It's very different from the climate change caused by the meteorite 65 million years ago that killed the dinosaurs, and it's different from the global warming today -- this global cooling was a gentle nudge. There was less stress."

It's tempting to think that today's global warming could be solved by replicating the dust shower that triggered global cooling 466 million years ago. But Heck says he would be cautious: "Geoengineering proposals should be evaluated

very critically and very carefully, because if something goes wrong, things could become worse than before."

While Heck isn't convinced that we've found the solution to climate change, he says it's a good idea for us to be thinking along these lines.

"We're experiencing global warming, it's undeniable," says Heck. "And we need to think about how we can prevent catastrophic consequences, or minimize them. Any idea that's reasonable should be explored."

Journal Reference: Birger Schmitz, K.A. Farley, S. Goderis, P.R. Heck, S.M. Bergström, S. Boschi, P. Claeys, V. Debaille, A. Dronov, M. Van Ginneken, D.A.t. Harper, F. Iqbal, J. Friberg, S. Liao, E. Martin, M.M.M. Meier, B. Peucker-Ehrenbrink, B. Soens, R. Wieler and F. Terfelt. An extraterrestrial trigger for the mid-Ordovician ice age: Dust from the breakup of the L-chondrite parent body. *Science Advances*, 2019 DOI: 10.1126/sciadv.aax4184.

Geochemists measure new composition of Earth's mantle

Researchers suspect greater dynamics than previously assumed between the Earth's surface and its mantle

ScienceDaily, September 16, 2019
Source: University of Mùnster

What is the chemical composition of the Earth's interior? Because it is impossible to drill more than about ten kilometres deep into the Earth, volcanic rocks formed by melting Earth's deep interior often provide such information. Geochemists at the Universities of Münster (Germany) and Amsterdam (Netherlands) have investigated the volcanic rocks that build up the Portuguese island group of the Azores. Their goal: gather new information about the compositional evolution of the Earth's mantle, which is the layer roughly between 30 and 2,900 kilometres deep inside the Earth. Using sophisticated analytical techniques, they discovered that the composition of the mantle below the Azores is different than previously thought -suggesting that large parts of it contain surprisingly few so-called incompatible elements. These are chemical elements which, as a result of the constant melting of the Earth's mantle, accumulate in the Earth's crust, which is Earth's outermost solid layer.

The researchers conclude that, over Earth's history, a larger amount of Earth's mantle has melted -- and ultimately formed the Earth's crust -- than previously thought. "To sustain the material budget between Earth's mantle and crust, mass fluxes between the surface and Earth's interior must have operated at a higher rate," says Münster University's Prof. Andreas Stracke, who is heading the study.

As the material below the Azores rises from very deep within Earth's mantle -- and is unexpectedly similar to most of its upper part -- the composition of Earth's entire mantle may differ from current thinking. "Our results have opened up a new perspective," says Andreas Stracke, "because we will now have to reassess the composition of the largest part of the Earth -- after all, Earth's mantle accounts for over 80 percent of Earth's volume." The study has been published in the journal Nature Geoscience.

Background and method

In their study, the geochemists examined the mineral olivine and its melt inclusions, i.e. magma encapsulated during the crystallisation of olivine before the lavas erupted. The researchers isolated these melt inclusions, just a few micrometers in size, dissolved them chemically and separated certain chemical elements. These elements are altered by radioactive decay during their lifetime and ascent from Earth's interior -- travelling over thousands of kilometres for hundreds or even thousands of millions of years.

The researchers analysed the isotopic composition of the melts with highly sensitive mass spectrometers. Such methods allow measurement of the relative abundance of different atoms in an element -- so-called isotopes. "Owing to the high efficiency of our measurements, we were able to analyse the isotopic composition of one billionth of a gram of the element," says co-author Dr. Felix Genske from the University of Münster's Institute of Mineralogy, who carried out most of the analytical work. In this way, the researchers indirectly obtained information on the composition of the material in the Earth's mantle: the isotope analyses showed that it contains far fewer rare Earth elements such as samarium and neodymium, but also of chemically similar elements such as thorium and uranium.

"On the basis of similar geochemical data in volcanic rocks from different regions, e.g. Hawaii, other parts of the Earth's mantle may also contain a higher proportion of material that is strongly depleted in incompatible elements," says Andreas Stracke. The researchers presume that this global deficit may be compensated by a higher rate of recycling Earth's incompatible element-rich crust back into Earth's mantle. With their continuing studies the researchers want to confirm their working hypothesis by investigating samples from other volcanic islands across the globe.

Journal Reference: Andreas Stracke, Felix Genske, Jasper Berndt, Janne M. Koornneef. Ubiquitous ultra-depleted domains in Earth’s mantle. Nature Geoscience, 2019; DOI: 10.1038/s41561-019-0446-z.

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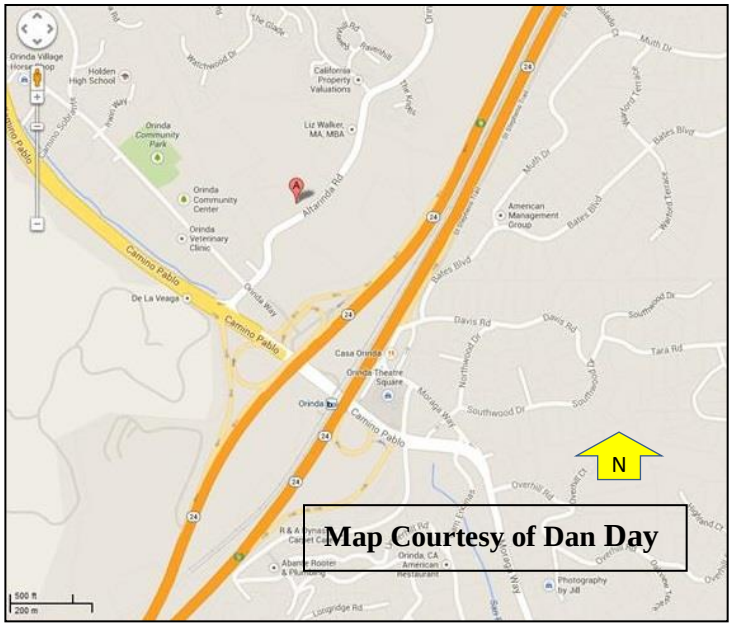

(continued from Page 1)
workers have included the Mt Diablo anticline in a fold and thrust belt rooted in a blind Mt Diablo Thrust extending beneath the mountain and ~20 km to the east. This neglects the 15 km strike-slip offset on the GDCFZ, however, and there is significantly less compressive deformation to the east. The model proposed here is that the Mt Diablo Thrust roots into the GDCFZ at depth, and the fold and thrust belt lies entirely to the west, limiting the area of fault rupture (and maximum earthquake) on the Mt Diablo Thrust. The Late Cretaceous and Paleogene stratigraphy at Mt Diablo shows that there is now a mountain where once was the depocenter of the Great Valley forearc basin.

Biography:

Dr. Graymer received his B.S. from Caltech in 1985, followed by a Ph.D. in 1992 from UC Berkeley (Structural Evolution of the Central Part of the Foothills Terrane, Sierra Nevada, California), and a Post-Doc in 1992-1994 at UC Berkeley (Is the Mission Fault the Calaveras-Hayward fault connection?). Then various teaching and consulting from 1994-1996. He has been at USGS from 1996 to the present, working on various topics including SF Bay region geologic mapping, NorCal Landslide Hazards Working Group, Bay Area 3D geologic map, San Andreas Fault 3D/4D geologic map, Delta 3D geologic map and seismic velocity model, Central California Coast Ranges 3D geologic map and seismic velocity model).

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