NORTHERN CALIFORNIA GEOLOGICAL SOCIETY

MEETING ANNOUNCEMENT

DATE: **Wednesday, September 25, 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. Douglas Dreger, UC Berkeley***

TOPIC: ***"Exotic Seismic Sources: Nuclear explosions, mining events, volcanic and geothermal seismicity, and a landslide"***

A seismic moment tensor is a description of the force system involved in the excitation of seismic waves in the Earth. The Berkeley Seismological Laboratory has been routinely computing seismic moment tensors of earthquakes in near-realtime for nearly three decades using three-component, long-period complete waveforms recorded at local and regional distances, yielding the refined estimate of Moment Magnitude, as well as fault parameters (strike, slip and dip). This analysis has contributed to an extensive catalog of moment tensor solutions for the central and northern California region, and the automatic and reviewed moment tensor solutions are used in shared emergency response monitoring with the USGS. The moment tensor method is also applied to non-tectonic sources of seismic energy, which show interesting differences from earthquakes. In this talk I will describe the development of methods for studying earthquakes and non-tectonic seismic events, and draw on a variety of examples from ice quakes, nuclear explosions, landslides, and the Ridgecrest, California earthquakes.

Biography:

Professor Douglas Dreger is an earthquake seismologist interested in earthquakes and other sources of seismic energy, and how the generated seismic waves propagate through the Earth. He has published over 130 peer-reviewed papers on seismic wave propagation, earthquake source parameters, and earthquake source inverse methods. The automated seismic moment tensor method he developed for UC Berkeley is now used by various institutions within the US, in Japan, Italy, and Taiwan.

(continued on last page)

NCGS 2019 – 2020 Calendar

October 30 **7:00 pm**

Dr. Russell Graymer, USGS

Geologic and geophysical framework of Mt Diablo

November 20 **7:00 pm**
(1 week early because of Thanksgiving)

Dr. Dr. David P. Schwartz, USGS

Earthquakes in the East Bay

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 Trips

Starting soon, 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.

NCGS Outreach Opportunities

The NCGS outreach team plans to host a booth at two events of the Bay Area Science Festival this fall: In Hayward on Sat., October 26, and in San Francisco on Sat., November 2. If you're interested in helping to encourage the next generation of geologists, please

contact our Outreach Chair, Mark Petrofsky, at mpetrof @ hotmail.com.

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.

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 4 pm for most of the academic year, from late August through early May. On September 26, Kanani Lee of Lawrence Livermore National Laboratory will speak on ***From the inside, out: A mineral physics perspective of planets.*** 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, September 26 at 7 pm by Gabriel A. Reyes, USGS Biologist, on ***Bats in the West: Discoveries, Questions, and Future Research***, 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.

Why there's a 'sweet spot' depth for underground magma chambers

ScienceDaily, August 19, 2019
Source: Brown University

A new study reveals why the magma chambers that feed recurrent and often explosive volcanic eruptions tend to reside in a very narrow depth range within the Earth's crust. The findings, published in *Nature Geoscience*, could help scientists to better understand volcanic processes the world over.

The research makes use of computer models that capture the physics of how magma chambers, reservoirs in the crust that contain partially molten rock, evolve over time. The models showed that two factors -- the ability of water vapor to bubble out of the magma, and the ability of the crust to expand to accommodate chamber growth -- are the key factors constraining the depth of magma chambers, which are generally found between six and 10 kilometers deep.

"We know from observations that there seems to be a sweet spot in terms of depth for magma chambers that erupt repeatedly," said Christian Huber, a geologist at Brown University and the study's lead author. "Why that sweet spot exists has been an open question for a long time, and this is the first study that explains the processes that control it."

Depths of six to 10 kilometers generally correspond to pressures of about 1.5 kilobars on the shallow side and 2.5

kilobars on deep side. The models showed that at pressures less than 1.5 kilobars, water trapped within the magma forms bubbles readily, leading to violent volcanic explosions that blast more magma out of a chamber than can be replaced. These chambers quickly cease to exist. At pressures more than 2.5 kilobars, warm temperatures deep inside the Earth make the rocks surrounding the magma chamber soft and pliable, which enables the chamber to grow comfortably without erupting to the surface. These systems cool and solidify over time without ever erupting.

"Between 1.5 and 2.5, the systems are happy," Huber said. "They can erupt, recharge and keep going."

The key to the models, Huber said, is that they capture the dynamics of both the host crust and of the magma in the chamber itself. The ability of deep magma chamber to grow without erupting was fairly well understood, but the limit that water vapor exerts on shallow magma chambers hadn't been appreciated.

"There hadn't been a good explanation for why this habitable zone should end at 1.5 kilobars," Huber said. "We show that the behavior of the gas is really important. It simply causes more mass to erupt out than can be recharged."

Huber says the findings will be helpful in understanding the global magma budget. "The ratio of magma that stays in the crust versus how much is erupted to the surface is a huge question," Huber said. "Magma supplies CO2 and other gases to the atmosphere, which influences the climate. So having a guide to understand what comes out and what stays in is important."

Coauthors on the paper Meredith Townsend, Wim Degruyter and Olivier Bachmann. The work was supported by the National Science Foundation (NSF-EAR 1760004) and the Swiss National Fund (200021_178928).

Journal Reference: Christian Huber, Meredith Townsend, Wim Degruyter, Olivier Bachmann. **Optimal depth of subvolcanic magma chamber growth controlled by volatiles and crust rheology.** *Nature Geoscience*, 2019; DOI: 10.1038/s41561-019-0415-6.

Geology of Leonardo's Virgin of the Rocks

By Steven Wade Veatch

From the Colorado Springs Mineralogical Society newsletter Pick & Pack, *Vol. 58, # 4, May, 2018*

Leonardo da Vinci 's Virgin of the Rocks (1483-1486). From his studies of geology, Leonardo learned how the Earth works and improved the realism of his paintings. Location: Louvre, Paris. Oil on panel transferred to canvas. Height: 199 cm (78.3 in). Width: 122 cm (48 in). *Image is in the public domain*.

Leonardo da Vinci (1452-1519), considered to be one of the greatest painters of all time, used his knowledge of geology to inform his art. Leonardo was also noted for his work in sculpture, anatomy, mathematics, architecture, and engineering during the Italian Renaissance (about 1330 to 1450).

From a geological perspective, Leonardo da Vinci's paintings present a realistic portrayal of nature. In his Virgin of the Rocks (1483-1486), on display in the Louvre in Paris, the geological accuracy is striking (Pizzorusso, 1996). The painting's subject is both the Virgin and the rocks. The Virgin sits in front of a grotto or cave. Various aspects of the grotto, according to geologist Ann Pizzorusso (1996), "are rendered with astounding geological accuracy. Leonardo has painted a rich earthscape of rock eroded and sculpted by the active geological forces of wind and water. Most of the rock formations . . . are weathered sandstone, a sedimentary rock."

What looks like basalt, an extrusive igneous rock formed by the cooling of lava, appears above Mary's head and at the top right of the picture. Leonardo even painted the columnar joints formed by the cooling of the rocks. Also, just above her head is a precisely painted seam between

the sandstone and igneous formations, and a rock joint runs horizontally to the right of her head. Art historians believe that the landscape in this painting is not an actual place, but one conjured up by Leonardo's experience, understanding of geology, and observation (lssacson, 2017).

A second version of the painting, also called the Virgin of the Rocks (1495-1508), is exhibited in the National Gallery in London. This painting fails to depict such a faithful rendering of geology as the one in Paris. Despite decades of analysis by scholars, there are doubts that it is an authentic Leonardo painting, but rather a copy of the original painting by another artist. Leonardo da Vinci was ahead of his time in his understanding of geology, and he recorded his observations in notebooks and journals (Bressan, 2014). After his death, his notebooks ended up on the bookshelves in libraries and private collections throughout Europe, while other notebooks disappeared into history (Waggoner, 1996). [Leonardo] wrote in one of his notebooks, the Codex Leicester, about the fossils he found as he walked the countryside.

Leonardo recognized that fossils were the remains of once-living organisms and relics of former times and other worlds – traces of a past hidden to other thinkers of the time. Leonardo also observed that distinct layers of rocks and fossils covered large areas, and the layers were formed at separate times--not in the single biblical flood (lssacson, 2017). And centuries before Darwin, Leonardo conjectured through his understanding of rocks, fossils, and the slow processes of erosion and deposition that the world is much older than what church fathers proclaimed (Jones, 2011).

Leonardo da Vinci's observations of fossils found on the tops of mountains wore a path through his thoughts. Since fossils are found in the mountains, the surface of the Earth, Leonardo posited, has changed over time. For example, an ancient sea is now dry land (Jones, 2011). Leonardo concluded that as mountains formed, they lifted marine sediments--carrying fossil-bearing rocks skyward to become mountain peaks. Today, geologists know that tectonic plates and other geological processes form mountains.

In another of his notebooks, the Codex Arundel, now housed in the British Library, Leonardo describes graded bedding in layers of sedimentary rocks (Pedretti, 1998). He also had a basic understanding of the superposition of rock strata, where the oldest rocks in a sequence of sedimentary rocks are at the bottom. This concept would not be recognized until the second half of the 17th century when Danish geologist Nicolas Steno, carrying the light of learning, took up the subject in 1669, laying the foundation for modern stratigraphy and geological mapping (Capra, 2013). Leonardo never published his theories. He only wrote his observations in his notebooks, which ended up scattered or lost. For more than three hundred years, his notes were not part of the progression of science. It was left for future scientists to rediscover Leonardo's observations on the vastness of geological time, sedimentary layering, and the significance of fossils, and to make these discoveries part of science.

Leonardo da Vinci's endless curiosity and boundless creativity made him the quintessential Renaissance man. He was a keen observer of nature whose interest led him to paint nature not only beautifully, but accurately.

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Researchers unearth 'new' mass-extinction

New analysis brings total of species extinctions to six

ScienceDaily, September 9, 2019
Source: New York University

A team of scientists has concluded that earth experienced a previously underestimated severe mass-extinction event, which occurred about 260 million years ago, raising the total of major mass extinctions in the geologic record to six.

"It is crucial that we know the number of severe mass extinctions and their timing in order to investigate their causes," explains Michael Rampino, a professor in New York University's Department of Biology and a co-author of the analysis, which appears in the journal *Historical Biology*. "Notably, all six major mass extinctions are correlated with devastating environmental upheavals -- specifically, massive flood-basalt eruptions, each covering more than a million square kilometers with thick lava flows."

Scientists had previously determined that there were five major mass-extinction events, wiping out large numbers of species and defining the ends of geological periods: the end of the Ordovician (443 million years ago), the Late Devonian (372 million years ago), the Permian (252 million years ago), the Triassic (201 million years ago), and the Cretaceous (66 million years ago). And, in fact, many researchers have raised concerns about the contemporary, ongoing loss of species diversity -- a development that might be labeled a "seventh extinction" because such a modern mass extinction, scientists have predicted, could end up being as severe as these past events.

The Historical Biology work, which also included Nanjing University's Shu-zhong Shen, focused on the Guadalupian, or Middle Permian period, which lasted from 272 to about 260 million years ago.

Here, the researchers observe, the end-Guadalupian extinction event -- which affected life on land and in the seas -- occurred at the same time as the Emeishan flood-basalt eruption that produced the Emeishan Traps, an extensive rock formation, found today in southern China. The eruption's impact was akin to those causing other known severe mass extinctions, Rampino says.

"Massive eruptions such as this one release large amounts of greenhouse gases, specifically carbon dioxide and methane, that cause severe global warming, with warm, oxygen-poor oceans that are not conducive to marine life," he notes.

"In terms of both losses in the number of species and overall ecological damage, the end-Guadalupian event now ranks as a major mass extinction, similar to the other five," the authors write.

Journal Reference: Michael R. Rampino, Shu-Zhong Shen. The end-Guadalupian (259.8 Ma) biodiversity crisis: the sixth major mass extinction? *Historical Biology*, 2019; 1 DOI: 10.1080/08912963.2019.1658096.

Evolution of life in the ocean changed 170 million years ago

ScienceDaily, July 25, 2019
Source: University of Plymouth

The ocean as we understand it today was shaped by a global evolutionary regime shift around 170 million years ago, according to new research.

Until that point, the success of organisms living within the marine environment had been strongly controlled by non-biological factors, including ocean chemistry and climate.

However, from the middle of the Jurassic period onwards (some 170 million years ago), biological factors such as predator-prey relationships became increasingly important.

Writing in Nature Geoscience, scientists say this change coincided with the proliferation of calcium carbonate-secreting plankton and their subsequent deposition on the ocean floor.

They believe the rise of this plankton stabilised the chemical composition of the ocean and provided the conditions for one of the most prominent diversifications of marine life in Earth's history.

The research was led by academics from the University of Plymouth's School of Geography, Earth and Environmental Sciences and School of Computing, Electronics and Mathematics, in cooperation with scientists from the University of Bergen in Norway, and the University of Erlangen-Nuremberg in Germany.

PhD candidate Kilian Eichenseer, the study's lead author, explained the impact of calcifying plankton: "Today, huge areas of the ocean floor are covered with the equivalent of chalk, made up of microscopic organisms that rose to dominance in the middle of the Jurassic period. The chalky mass helps to balance out the acidity of the ocean and, with that balance in place, organisms are less at the mercy of short-term perturbations of ocean chemistry than they might have been previously. It is easier to secrete a shell, regardless of its mineralogy, if the ocean chemistry is stable."

The aim of the research was to test the hypothesis that the evolutionary importance of the non-biological environment had declined through geological time. Since its emergence more than 540 million years ago, multicellular life evolved under the influence of both the non-biological and the biological environment, but how the balance between these factors changed remained largely unknown.

Calcified seashells provide an ideal test to answer this question, as aragonite and calcite -- the minerals making up seashells -- also form non-biologically in the ocean. In

their study, the authors used the vast global fossil record of marine organisms that secreted calcium carbonate, which encompasses more than 400,000 samples dating from 10,000 years BC up to around 500 million years ago.

Using reconstructions of the temperature and the ocean water composition of the past, the authors estimated the proportion of aragonite and calcite that formed inorganically in the ocean in 85 geological stages across 500 million years.

Through a series of specially developed statistical analyses, this inorganic pattern of aragonite-calcite seas was then compared with seashell mineral composition over the same time.

The results show that up until the middle of the Jurassic period, around 170 million years ago, the ecological success of shell-secreting marine organisms was tightly coupled to their shell composition: organisms that secreted the mineral that was environmentally favoured had an evolutionary advantage.

However, the Earth-Life system was revolutionised forever by the rise of calcifying plankton, which expanded the production of calcium carbonate from continental shelves to the open ocean.

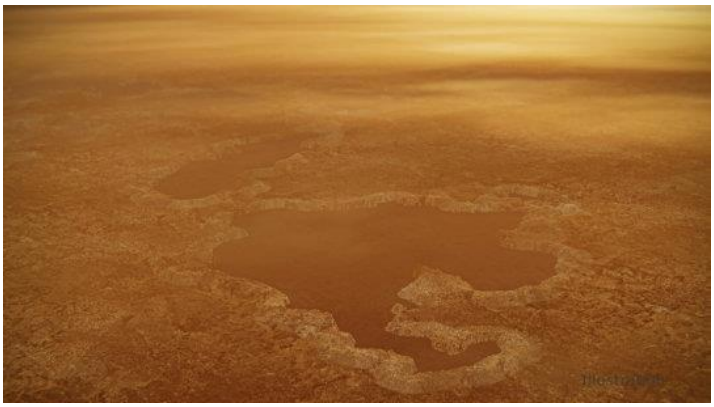
This ensured that the evolutionary impact of episodes of severe climate changes, and resulting ocean acidification, was less severe than comparable events earlier in Earth history.

Dr Uwe Balthasar, Lecturer in Palaeontology, first published research exploring the dominance of aragonite and calcite in the marine environment in 2015. He said: "During the Earth's history there have been several major events that shaped the evolution of life on our planet, such as the five big mass extinctions or the radiation of complex animals during the 'Cambrian Explosion'. Our research identifies a previously overlooked event of this magnitude around 170 million years ago when the emergence of calcium carbonate-secreting plankton lifted constraints on the evolution of other marine organisms that we did not know existed. As a result, life in the ocean has diversified to levels far beyond what existed before."

Journal Reference: Kilian Eichenseer, Uwe Balthasar, Christopher W. Smart, Julian Stander, Kristian A. Haaga, Wolfgang Kiessling. **Jurassic shift from abiotic to biotic control on marine ecological success.** *Nature Geoscience*, 2019; DOI: 10.1038/s41561-019-0392-9.

Lakes on Saturn's moon Titan are explosion craters, new models suggest

ScienceDaily, September 10, 2019
Source: NASA/Jet Propulsion Laboratory



This artist's concept of a lake at the north pole of Saturn's moon Titan illustrates raised rims and rampartlike features such as those seen by NASA's Cassini spacecraft around the moon's Winnipeg Lacus. *Credit: NASA/JPL-Caltech*

Using radar data from NASA's Cassini spacecraft, recently published research presents a new scenario to explain why some methane-filled lakes on Saturn's moon Titan are surrounded by steep rims that reach hundreds of feet high. The models suggests that explosions of warming nitrogen created basins in the moon's crust.

Titan is the only planetary body in our solar system other than Earth known to have stable liquid on its surface. But instead of water raining down from clouds and filling lakes and seas as on Earth, on Titan it's methane and ethane -- hydrocarbons that we think of as gases but that behave as liquids in Titan's frigid climate.

Most existing models that lay out the origin of Titan's lakes show liquid methane dissolving the moon's bedrock of ice and solid organic compounds, carving reservoirs that fill with the liquid. This may be the origin of a type of lake on Titan that has sharp boundaries. On Earth, bodies of water that formed similarly, by dissolving surrounding limestone, are known as karstic lakes.

The new, alternative models for some of the smaller lakes (tens of miles across) turns that theory upside down: It proposes pockets of liquid nitrogen in Titan's crust warmed, turning into explosive gas that blew out craters, which then filled with liquid methane. The new theory explains why some of the smaller lakes near Titan's north pole, like Winnipeg Lacus, appear in radar imaging to have very steep rims that tower above sea level -- rims difficult to explain with the karstic model.

The radar data were gathered by the Cassini Saturn Orbiter -- a mission managed by NASA's Jet Propulsion Laboratory in Pasadena, California -- during its last close

flyby of Titan, as the spacecraft prepared for its final plunge into Saturn's atmosphere two years ago. An international team of scientists led by Giuseppe Mitri of Italy's G. d'Annunzio University became convinced that the karstic model didn't jibe with what they saw in these new images.

"The rim goes up, and the karst process works in the opposite way," Mitri said. "We were not finding any explanation that fit with a karstic lake basin. In reality, the morphology was more consistent with an explosion crater, where the rim is formed by the ejected material from the crater interior. It's totally a different process."

The work, published Sept. 9 in Nature Geoscience, meshes with other Titan climate models showing the moon may be warm compared to how it was in earlier Titan "ice ages."

Over the last half-billion or billion years on Titan, methane in its atmosphere has acted as a greenhouse gas, keeping the moon relatively warm -- although still cold by Earth standards. Scientists have long believed that the moon has gone through epochs of cooling and warming, as methane is depleted by solar-driven chemistry and then resupplied.

In the colder periods, nitrogen dominated the atmosphere, raining down and cycling through the icy crust to collect in pools just below the surface, said Cassini scientist and study co-author Jonathan Lunine of Cornell University in Ithaca, New York.

"These lakes with steep edges, ramparts and raised rims would be a signpost of periods in Titan's history when there was liquid nitrogen on the surface and in the crust," he noted. Even localized warming would have been enough to turn the liquid nitrogen into vapor, cause it to expand quickly and blow out a crater.

"This is a completely different explanation for the steep rims around those small lakes, which has been a tremendous puzzle," said Cassini Project Scientist Linda Spilker of JPL. "As scientists continue to mine the treasure trove of Cassini data, we'll keep putting more and more pieces of the puzzle together. Over the next decades, we will come to understand the Saturn system better and better."

The Cassini-Huygens mission is a cooperative project of NASA, ESA (the European Space Agency) and the Italian Space Agency. JPL, a division of Caltech in Pasadena, manages the mission for NASA's Science Mission Directorate in Washington. JPL designed, developed and assembled the Cassini orbiter. The radar instrument was built by JPL and the Italian Space Agency, working with team members from the U.S. and several European countries.

More information about Cassini can be found here: https://solarsystem.nasa.gov/cassini.

Journal Reference: Giuseppe Mitri, Jonathan I. Lunine, Marco Mastrogiuseppe, Valerio Poggiali. Possible explosion crater origin of small lake basins with raised rims on Titan. *Nature Geoscience*, 2019; DOI: 10.1038/s41561-019-0429-0.

Origin of massive methane reservoir identified

ScienceDaily, August 20, 2019
Source: Woods Hole Oceanographic Institution

New research from Woods Hole Oceanographic Institution (WHOI) published Aug. 19, 2019, in the *Proceedings of the National Academy of Science* provides evidence of the formation and abundance of abiotic methane -- methane formed by chemical reactions that don't involve organic matter -- on Earth and shows how the gases could have a similar origin on other planets and moons, even those no longer home to liquid water. Researchers had long noticed methane released from deep-sea vents. But while the gas is plentiful in the atmosphere where it's produced by living things, the source of methane at the seafloor was a mystery.

"Identifying an abiotic source of deep-sea methane has been a problem that we've been wrestling with for many years," says Jeffrey Seewald a senior scientist at WHOI who studies geochemistry in hydrothermal systems and is one of the study's authors.

Of 160 rock samples analyzed from across the world's oceans, almost all contained pockets of methane. These oceanic deposits make up a reservoir exceeding the amount of methane in Earth's atmosphere before industrialization, estimates Frieder Klein, a marine geologist at WHOI and lead author of the study.

"We were totally surprised to find this massive pool of abiotic methane in the oceanic crust and mantle," Klein says.

The scientists analyzed rocks using Raman spectroscopy, a laser-based microscope that allows them to identify fluids and minerals in a thin slice of rock. Nearly every sample contained an assemblage of minerals and gases that form when seawater, moving through the deep oceanic crust, is trapped in magma-hot olivine. As the mineral cools, the water trapped inside undergoes a chemical reaction, a process called serpentinization that forms hydrogen and methane. The authors demonstrate that in otherwise inhospitable environments, just two ingredients? -- water and olivine? -- can form methane.

"Here's a source of chemical energy that's being created by geology," says Seewald.

On Earth, deep-sea methane might have played a critical role for the evolution of primitive organisms living at hydrothermal vents on the seafloor, Seewald explains. And elsewhere in the solar system, on places like Jupiter's moon Europa and Saturn's Enceladus, methane produced through the same process could provide an energy source for basic life forms.

Journal Reference: Frieder Klein, Niya G. Grozeva, Jeffrey S. Seewald. Abiotic methane synthesis and serpentinization in olivine-hosted fluid inclusions. *Proceedings of the National Academy of Sciences*, 2019; 201907871 DOI: 10.1073/pnas.1907871116.

Ancient animal species: Fossils dating back 550 million years among first animal trails

ScienceDaily, September 4, 2019
Source: Virginia Tech University

In a remarkable evolutionary discovery, a team of scientists co-led by a Virginia Tech geoscientist has discovered what could be among the first trails made by animals on the surface of the Earth roughly a half-billion years ago.

Shuhai Xiao, a professor of geosciences with the Virginia Tech College of Science, calls the unearthed fossils, including the bodies and trails left by an ancient animal species, the most convincing sign of ancient animal mobility, dating back about 550 million years. Named Yilingia spiciformis -- that translates to spiky Yiling bug, Yiling being the Chinese city near the discovery site -- the animal was found in multiple layers of rock by Xiao and Zhe Chen, Chuanming Zhou, and Xunlai Yuan from the Chinese Academy of Sciences' Nanjing Institute of Geology and Palaeontology.

The findings are published in the latest issue of Nature. The trails are from the same rock unit and are roughly the same age as bug-like footprints found by Xiao and his team in a series of digs from 2013 to 2018 in the Yangtze Gorges area of southern China, and date back to the Ediacaran Period, well before the age of dinosaurs or even the Pangea supercontinent. What sets this find apart: The preserved fossil of the animal that made the trail versus the unknowable guesswork where the body has not been preserved.

"This discovery shows that segmented and mobile animals evolved by 550 million years ago," Xiao said. "Mobility made it possible for animals to make an unmistakable footprint on Earth, both literally and metaphorically. Those are the kind of features you find in a group of animals called bilaterans. This group includes us humans and most animals. Animals and particularly humans are movers and shakers on Earth. Their ability to shape the face of the planet is ultimately tied to the origin of animal motility."

The animal was a millipede-like creature a quarter-inch to an inch wide and up to 4 inches long that alternately dragged its body across the muddy ocean floor and rested along the way, leaving trails as loing as 23 inches. The animal was an elongated narrow creature, with 50 or so body segments, a left and right side, a back and belly, and a head and a tail.

The origin of bilaterally symmetric animals -- known as bilaterians -- with segmented bodies and directional mobility is a monumental event in early animal evolution, and is estimated to have occurred the Ediacaran Period, between 635 and 539 million years ago. But until this finding by Xiao and his team, there was no convincing fossil evidence to substantiate those estimates. One of the recovered specimens is particularly vital because the animal and the trail it produced just before its death are preserved together.

Remarkably, the find also marks what may be the first sign of decision making among animals -- the trails suggest an effort to move toward or away from something, perhaps under the direction of a sophisticated central nerve system, Xiao said. The mobility of animals led to environmental and ecological impacts on the Earth surface system and ultimately led to the Cambrian substrate and agronomic revolutions, he said.

"We are the most impactful animal on Earth," added Xiao, also an affiliated member of the Global Change Center at Virginia Tech. "We make a huge footprint, not only from locomotion, but in many other and more impactful activities related to our ability to move. When and how animal locomotion evolved defines an important geological and evolutionary context of anthropogenic impact on the surface of the Earth."

Rachel Wood, a professor in the School of GeoSciences at University of Edinburgh in Scotland, who was not involved with the study, said, "This is a remarkable finding of highly significant fossils. We now have evidence that segmented animals were present and had gained an ability to move across the sea floor before the Cambrian, and more notably we can tie the actual trace-maker to the trace. Such preservation is unusual and provides considerable insight into a major step in the evolution of animals."

The study was supported by the Chinese Academy of Sciences, the National Natural Science Foundation of

China, the U.S. National Science Foundation, and the National Geographic Society.

Journal Reference: Zhe Chen, Chuanming Zhou, Xunlai Yuan, Shuhai Xiao. Death march of a segmented and trilobate bilaterian elucidates early animal evolution. *Nature*, 2019; DOI: 10.1038/s41586-019-1522-7.

How to recognize where a volcano will erupt

New method to forecast vents tested on one of the Earth's highest-risk volcanoes

ScienceDaily, July 31, 2019
Source: GFZ GeoForschungsZentrum Potsdam, Helmholtz Centre

Most of the times you see the eruption of a volcano on TV or the internet, the magma shoots right out of its top. However, it is not so uncommon that the magma erupts from the volcano's flank rather than its summit. After leaving the underground magma chamber, the magma forces its way sideways by fracturing rock, sometimes for tens of kilometres. Then, when it breaches the Earth's surface, it forms one or more vents from which it spills out, sometimes explosively. This for example occurred at Bardarbunga in Iceland in August 2014, and Kilauea in Hawaii in August 2018.

It is a big challenge for volcanologists to guess where magma is heading and where it will breach the surface. A lot of effort is spent on this task as it could help minimise the risk for villages and cities endangered by eruptions. Now, Eleonora Rivalta and her team from the GFZ German Research Centre for Geosciences in Potsdam, together with colleagues from the University Roma Tre and the Vesuvius Observatory of the Italian Istituto Nazionale di Geofisica e Vulcanologia in Naples have devised a new method to generate vent location forecasts. The study is published in the journal Science Advances.

"Previous methods were based on the statistics of the locations of past eruptions," says Eleonora Rivalta. "Our method combines physics and statistics: we calculate the paths of least resistance for ascending magma and tune the model based on statistics." The researchers successfully tested the new approach with data from the Campi Flegrei caldera in Italy, one of the Earth's highest-risk volcanoes.

"Calderas often look like a lawn covered in molehills"

Vents opened at the flank of a volcano are often used by just one eruption. All volcanoes may produce such one-time vents, but some do more than others. Their flanks are punctured by tens of vents whose alignment marks the locations where subsurface magma pathways have intersected the Earth's surface.

At calderas, that is large cauldron-like hollows that form shortly after the emptying of a magma chamber in a volcanic eruption, vents may also open inside and on its rim. That is because they lack a summit to focus eruptions. "Calderas often look like a lawn covered in molehills," says GFZ's Eleonora Rivalta.

Most vents at calderas have only been used once. The resulting scattered, sometimes seemingly random spatial vent distribution threatens wide areas, presenting a challenge to volcanologists who draw forecast maps for the location of future eruptions. Such maps are also necessary for accurate forecasts of lava and pyroclastic flows or the expansion of ash plumes.

Vent forecast maps have so far been mainly based on the spatial distribution of past vents: "Volcanologists often assume that the volcano will behave like it did in the past," says Eleonora Rivalta. "The problem is that often only a few tens of vents are visible on the volcano surface as major eruptive episodes tend to cover or obliterate past eruptive patterns. Hence, as mathematically sophisticated as the procedure can be, sparse data lead to coarse maps with large uncertainties. Moreover, the dynamics of a volcano may change with time, so that vent locations will shift."

Succesful tests at the Campi Flegrei

That is why Rivalta, a trained physicist, together with a team of geologists and statisticians, used volcano physics to improve the forecasts. "We employ the most up-to-date physical understanding of how magma fractures rock to move underground and combine it with a statistical procedure and knowledge of the volcano structure and history. We tune the parameters of the physical model until they match previous eruptive patterns. Then, we have a working model and can use it to forecast future eruption locations," says Eleonora Rivalta.

The new approach was applied in southern Italy to the Campi Flegrei, a caldera close to Naples, which has a population of nearly one million. In the more than ten kilometres wide caldera, about eighty vents have fed explosive eruptions in the last 15,000 years. The approach performs well in retrospective tests, that is correctly forecasting the location of vents that were not used to tune the model, the researchers report.

"The most difficult part was to formulate the method in a way that works for all volcanoes and not just one -- to generalise it," Rivalta explains. "We will now perform more tests. If our method works well on other volcanoes too, it may help planning land usage in volcanic areas and forecasting the location of future eruptions with a higher certainty than previously possible."

Journal Reference: Rivalta, E., Corbi, F., Passarelli, L., Acocella, V., Davis., T., Di Vito, M.A. **Stress inversions**

to forecast magma pathways and eruptive vent location. *Science Advances*, 2019 DOI: 10.1126/sciadv.aau9784.

Electricity-driven undersea reactions may have been important for the emergence of life

Team discovers unusual chemical reactions in deep sea environment laboratory simulations

ScienceDaily, July 25, 2019
Source: Tokyo Institute of Technology

Though it remains unknown how life began, there is a community of scientists who suspect it occurred in or around deep sea hydrothermal environments.

At such sites, water heated by contact with hot rocks from Earth's mantle flows into the lower ocean, passing over and through minerals which are themselves precipitated by the interaction of this hot water with cold seawater. The minerals often include metal sulfides, such as iron sulfide, also known as pyrite or fool's gold. As they precipitate, these mineral precipitates begin to form channels for the hot vent water, and since the metal-containing minerals are electrically conductive and the compositions of the vent water and ocean water are different, an electrical gradient is created -- something like a natural battery -- with electric current flowing from the vent water through the minerals and into the ocean.

A team led by Tokyo Institute of Technology/Earth-Life Science Institute (ELSI) scientists have now shown via careful laboratory experiments that this current can reduce the metal sulfide minerals to native metals and mixed metal sulfide/metal conglomerates, which in turn can reduce and catalyze the reduction of various organic compounds.

The team led by Norio Kitadai, an affiliated scientist of the Tokyo Institute of Technology/Earth-Life Science Institute (ELSI) as well as a scientist at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), produced a set of electrochemical reactions in the laboratory that are suspected to have been generated in early ocean floor hydrothermal vent environments. They demonstrated that metal sulfides, including those of iron, copper, lead, and silver (some of which are common constituent minerals in hydrothermal vent environments), were converted to native metals by electroreduction. Complexes of metal sulfide and reduced metal were also produced during the process. It was also discovered that several organic chemical reactions indispensable in modern life were promoted by these complexes. The authors believe the metals and metal sulfides served as reducing agents and catalysts for these reactions.

This research identifies a new mechanism for the creation of organic compounds driven by hydrothermal electricity generation in hydrothermal fluids. An exciting implication of this work is that, since electrical current appears to be universally generated in deep-sea hydrothermal vent environments on Earth, anywhere such hydrothermal processes occur throughout the cosmos should likewise promote this kind of chemistry. Indeed, recent astronomical and spacecraft-based observations suggest there may be vigorous hydrothermal activity on the moons of Saturn and Jupiter (Enceladus and Europa), and hydrothermal activity was likely common on early Mars.

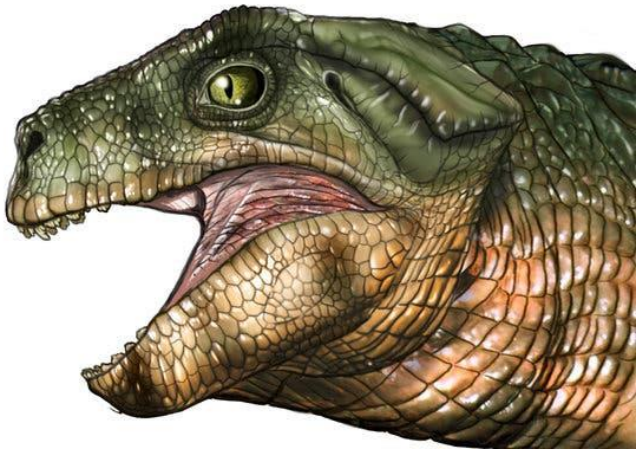
Further research on the effects of various metals and electric gradients is expected to unveil much more about the environmental conditions that can facilitate prebiotic chemistry. This could ultimately lead to a better understanding of the universality and similarity of life in the universe.

Journal Reference: Norio Kitadai, Ryuhei Nakamura, Masahiro Yamamoto, Ken Takai, Naohiro Yoshida, Yoshi Oono. **Metals likely promoted protometabolism in early ocean alkaline hydrothermal systems**. *Science Advances*, 2019; 5 (6): eaav7848 DOI: 10.1126/sciadv.aav7848.

Crocodiles Went Through a Vegetarian Phase, Too

Ancestors of modern crocodiles evolved to survive on a plant diet at least three times, researchers say.

By Cara Giaimo, The New York Times, June 27, 2019



The mighty, fearsome, frond-feasting crocodylomorph Simosuchus. Credit Jorge Gonzalez

Imagine you're a small mammal of the Mesozoic. Snuffling around one day, you run into a cat-size, scaly, big-eyed reptile that looks not unlike a crocodile found later in the 21st century. Spotting you, he opens his mouth wide to reveal … tiny, intricate teeth. Then he turns his head and munches on some leaves.

Such encounters may have been common in prehistory. Research published Thursday in *Current Biology* suggests that vegetarianism evolved at least three separate times in ancient crocs — a conclusion reached after scientists studied the unusual teeth sported by many species, including the Simosuchus described above.

Today, crocodiles and their relatives, among them alligators, caimans and gharials, can be found across the Southern hemisphere. They have many things in common, including meat-heavy diets, a penchant for swimming and their teeth. Ask them to smile for a family reunion photo, and each mouth would bristle with simple, blunt-tipped cones.

But the Mesozoic was a different story. About 250 million years ago, scores of crocodyliform species could be found across the globe, some on land and some in seas and rivers. A particular species might eat only plants, only animals, or both. To support these varied diets, many had "unique, interesting teeth," said Keegan Melstrom, a geobiology graduate student at the University of Utah and lead author of the new study.

A tooth can reveal a lot about its owner. Carnivores tend to have sharp, smooth teeth, used for biting and tearing. Herbivores must break down food in their mouths before they swallow, so their teeth are more complex, with many bumps and ridges. Omnivores, like us, are in the middle.

Mr. Melstrom has been keen on crocodile teeth since 2011, when he saw a presentation on an extinct crocodyliform called Pakasuchus. Pakasuchus had canines in the front of its mouth and molars in the back. When its jaw closed, the teeth would neatly slot together — more like a mammal's mouth than the akimbo grin of modern crocodiles. "It just blew my mind," Mr. Melstrom said.

For the new study, Mr. Melstrom and his co-author, Randall Irmis, analyzed 146 teeth from 16 extinct crocodyliform species. They used a method called orientation patch count rotated. From a scan of an object, the method generates a numerical score indicating the complexity of the object's shape. "It allows us to compare teeth that have no landmarks in common," said Mr. Melstrom.

This proved especially useful for studying prehistoric crocs, he said, whose teeth often have "no modern-day analogues." One of the few Chimaerasuchus teeth known to science has "at least two rows of seven cusps, each of those cusps varying in size," like a miniature mountain range in enamel. One species, Iharkutosuchus, had big square teeth cut through with deep grooves.

The researchers gathered the complexity scores of the teeth and compared them to those of living reptiles and mammals with known diets. Half of the ancient species seemed to have been on the plant-eating end of the spectrum — "a genuine surprise," Mr. Melstrom said.

What's more, several of them were from distinct lineages. This suggests to Mr. Melstrom that vegetarianism was not an anomaly in crocodyliform history, but evolved at least three times. In future research, he hopes to find out why vegetarian crocodyliforms didn't last past the end of the Cretaceous; the answer may relate to cooling climates, changes in plant life or competition with mammals, he said.

Scientists have speculated that herbivorous crocodyliforms may once have existed, but the new study provides "the first quantitative support" for the idea, said Attila Ősi, a vertebrate paleontologist at Eötvös Loránd University in Budapest, who was not involved in the study. These early crocodiles "could have been significant members of Mesozoic herbivore communities."

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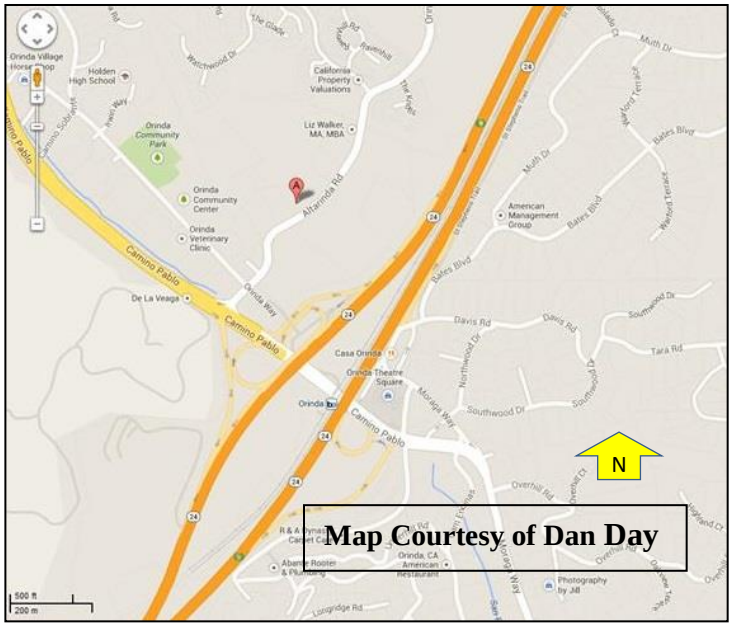

(continued from Page 1)

He attended UC Riverside earning a BS in Geophysics, and Caltech earning a MS in Geophysics and Ph.D. in Seismology, and has been affiliated with the Berkeley Seismological Laboratory since 1992. He teaches courses on geology, theoretical and observational seismology, and applied geophysics in the Department of Earth and Planetary Science.

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