NORTHERN CALIFORNIA GEOLOGICAL SOCIETY

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MEETING ANNOUNCEMENT

DATE: **Wednesday, January 31, 2024**

LOCATION: **Orinda Masonic Hall**

TIME: **Social: 6:30 to 7:15 pm; Program: 7:15 to 8:30 pm**

SPEAKER: ***Dr. Pallav Sarma, Co-Founder and CTO, Tachyus***

TOPIC: ***"Physics Embedded Machine Learning for Modeling and Optimization of Mature Fields"***

Abstract:

In traditional reservoir management, various types of predictive models have been applied over the years for either qualitative or quantitative optimization of various reservoir management decisions. Such models range from the simple analytical (type-curves, etc.) and machine models to the very complex reservoir simulation models. However, such tools are either too complex and time consuming to build and use or lack predictive capacity to be used reliably for large scale quantitative optimization. As such, there is a significant opportunity to enhance traditional reservoir management with new quantitative tools and technologies that allow integration of all kinds to data to create accurate predictive models while significantly reducing the cycle time from data to decisions.

This work describes a unique modeling approach termed Data Physics. Data Physics is the amalgamation of the state-of-the-art in machine learning and the same underlying physics present in reservoir simulators. These models can be created as efficiently as machine learning models, integrate all kinds of data, and can be evaluated orders of magnitude faster than full scale simulation models, and since they include similar underlying physics as simulators, they have good long term predictive capacity. We present applications of Data Physics models to a complex waterflood field in Argentina, wherein, the injectant is redistributed to maximize/minimize multiple objectives. A significant increase in actual incremental oil production and reduction in operational cost is demonstrated. Additional applications to infill drilling optimization and subsurface back allocation are also discussed.

Biography:

Dr. Pallav Sarma is Co-Founder and CTO at Tachyus, and responsible for the modeling and optimization technologies underlying the Tachyus platform. He is a renowned expert in closed-loop reservoir management, with multiple patents and papers on various topics including simulation,

(continued on last page)

NCGS 2023 – 2024 Calendar

February 28, 2024 7:15 pm (6:30 social hour)
Chris Bond, CA Department of Water Resources
DWR's California Aqueduct Subsidence Program (CASP) - addressing ongoing groundwater pumping induced subsidence while developing solutions and funding sources to proactively preserve the aqueduct's ability to deliver water for the next 75 years

March 27, 2024 7:15 pm (6:30 social hour)
Jessica Murray, U.S. Geological Survey
Inclusion of real-time Global Navigation Satellite System-based earthquake source characterization in the ShakeAlert earthquake early warning system to improve estimates of anticipated ground shaking and the alerts derived from them

April 24, 2024 7:15 pm (6:30 social hour)
Nicholas Swanson-Hysell, UC Berkeley
Chronostratigraphy of Miocene strata in the Berkeley Hills and the arrival of the San Andreas transform boundary

May 29, 2024 7:15 pm (6:30 social hour)
(Dinner meeting)
Libby Ives, Jet Propulsion Laboratory (NASA/Caltech)
Sedimentary geology of the Jezero crater western fan as seen by NASA's Mars Perseverance rover

June 26, 2024 7:15 pm (6:30 social hour)
Program TBD

New Youtube Channel:

By vote of the Board in May 2023, we returned to in-person meetings only, as of the September 2023 meeting. We will still record the meetings to Zoom for archiving on our new YouTube channel, @NCGS1000 (which you can access now by typing in the entire name @NCGS1000 into the search bar for Google or YouTube). This is where recently recorded talks can be accessed a few days after each meeting, or past talks recorded since September 2022 can be reviewed at any time. Only talks for which authors have given permission for this archiving will be accessible.

NCGS Officers Follow-Up

As you probably know, in June NCGS approved the slate of nominated officers to serve for 2023-2024. All these officers can always use extra help, and this is a good way to learn the ropes. Please contact Jim O'Brient if you have any interest in serving in any of the Officer or Committee roles. We would also like to acknowledge Chris McGuffin, who continues to help us with the audio-visual set-ups for our meetings.

Invitation For New Officer Appointment

Due to the recent resignation of our Secretary, Steve Self, for personal reasons, we are looking to appoint a new secretary to fill the rest of Steve's elected term (through August 31, 2024) and potentially to stand for re-election next June. Please contact President Jim O'Brient or Past President Noelle Schoellkopf if you are interested or have a candidate to suggest. The duties are few, but vitally important to the society:

(1) The **Recording Secretary** shall attend and take notes at all Executive Committee board meetings (typically three times per year) and shall notify the members of proposed amendments to the Constitution and Bylaws.
(2) When any other membership-wide communication is required, assist other officers in sending out email and occasional postal communications. Note: Since NCGS has moved to a new web-based system for emails, sign-ups, and payments (RegFox), this will chiefly be a consulting role to help others such as the President, Newsletter Editor, Treasurer, Membership Chair, Program Chair, or Field Trip Chair, all of whom will be trained on sending out such messages directly.
(3) Maintain Google drive folders and access for our archive of past information.
(4) Maintain hard cc files (as backup) only for critical Society records.
(5) Serve as alternate check signer when neither Treasurer nor President is available.

Website News

From Andrew Alden, NCGS Website Manager/Social Media

I continue to tweak and dink the NCGS website because working on it is so easy now. Most of the changes are small alterations of wording, but one change is up front on the home page. The middle column is now labeled "News" and lists recent developments wherever they appear on the site.

Remember, our URL no longer uses the "www" prefix; it's just ncgeolsoc.org. I've made corrections everywhere I can think of. Did you know that mindat.org has a listing for us? They responded promptly. You can help, too: If you see our old URL posted in your circles, perhaps on LinkedIn or another professional society's site, please speak up and see that it's corrected.

Thanks,

Andrew

K-12 GEOSCIENCE TEACHER OF THE YEAR AWARD FOR 2024 – $1,000

The Northern California Geological Society (NCGS) invites applications from candidates in Northern California for the 2024 K-12 Geoscience Teacher of the Year Award. Applications may be submitted by any K-12 teacher.

Applications should address teaching of units covering any of the earth or environmental sciences, including but not limited to mineralogy, petrology, economic geology, geomorphology, paleontology, hydrology, and planetary geology and are invited from physical science, earth science, and geology teachers.

The deadline for application submittal is **Saturday, March 2, 2024.**

The winner will receive a $1,000 award at a Northern California Geological Society dinner meeting in Orinda in late May 2024. Also, the awardee will be entered in the Pacific Section of the AAPG's competition, which has further benefits, and the winner of that award may subsequently be entered in the AAPG's national competition, which has substantial benefits. To apply, complete the application form, which is available on our website along with other relevant information:

https://ncgeolsoc.org/awards/

For any questions, contact Dr. Paul Henshaw at (925) 212-0402, or drphenshaw@comcast.net

NCGS Photo of the Month

We've posted some great photos provided by members on these pages in the past year to two. The editor wishes to encourage members to submit a photo or two of an interesting site or experience; the only requirement is that it have some at-least-tangential relation to geology.

Above: Nortonville Paralava: This was apparently a huge waste heap of mine debris full of coal and chunks of sedimentary rock. Exposed to oxygen, organic matter in such piles can spontaneously combust, and oxidation of pyrite, which is exothermic, can also cause combustion. Temperatures of 2,000 degrees C can be reached. Iron is oxidized to hematite, thus the reddish color, and rocks are melted, producing what has been called "paralava," which is evident in this photo. But it would be nice to know more of the actual history. Credit: Stephen Edwards

This month we're showing a photo from Stephen Edwards's excellent website, originally cited here a couple years ago. There's a wealth of fine photos of geology and botany with excellent explanations, such as the one above (like me, you may learn something completely new!), as well as beautiful views of scenery along with poetry. For a captivating tour of regional geology and botany, see his website at http://californiageology.net.

Loss of a Dear Colleague

NCGS sends its condolences and deep appreciation to his wife Barbara and his family for the passing of our departed friend, colleague, and respected leader for many years, Dr. Ray Sullivan, on Saturday, January 13, 2024. An obituary will appear in a future newsletter.

The Northern California Geological Society's

RICHARD CHAMBERS MEMORIAL SCHOLARSHIPS

2023-2024 AWARDS

The NCGS is pleased to announce that it is awarding $2,000 scholarships to two graduate students pursuing research in northern California. The availability of the Richard Chambers Memorial Scholarship is announced to all Colleges and Universities having graduate programs in northern California. These scholarships are funded from the Richard Chambers Memorial Scholarship fund and donations made by NCGS members and others for scholarships. These two students were chosen from a collection of well-prepared applications made to the NCGS during the fall of 2023. Serving on the NCGS Scholarship Committee were Phillip Garbutt (chair), Andrew Alden, Don Medwedeff, Noelle Schoellkopf and Will Schweller.

The recipients are:

Eden Pikowski, CSU Chico, for a master's research proposal titled ***"Paleoecology of the hydrocarbon seeps of Blue Ridge, Colusa, County, CA".*** Project advisor is Dr. Robert Shapiro.

Evelyn H. Usher, for a master's degree research proposal titled: ***"Transition from Walker Lane deformation to***

Cascade Range faulting and volcanism within Lassen National Park". Project advisor is Dr. Michael Oskin.

UC Berkeley Earth & Planetary Science Weekly Seminar Series

In-person EPS Seminar talks have resumed for the semester and are scheduled through early December. On Thursday, February 8, 2024 at 3:45 pm, Geoff Vallis, U. of Exeter will speak on ***Hothouse Climates and the Pole-Equator Temperature Gradient*** at 141 McCone Hall. To join the department's email list, send an email to eps_frontoffice@berkeley.edu. For updated listings of upcoming seminars, go to https://eps.berkeley.edu/seminars-courses/eps-seminars.

For the Rockhounds

For links to upcoming rock and mineral shows, go to www.cfmsinc.org/shows.

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. Pre-Covid, talks were held at USGS; the talks are now online. Talks are scheduled through April. On January 25 at 6:00 PM, Kathleen Springer and Jeff Pigati, USGS Geoscience & Environmental Change Science Center, will speak on ***Evidence of humans in North America during the last glacial maximum: Ancient human footprints at White Sands National Park and their evidence ofr the peopling of the Americas.*** Check the website to join the live stream, at: www.usgs.gov/pls/. To be added to the email notification list for future USGS Public Lecture Series events, please email: wmcesic@usgs.gov.

2023-2024 NCGS Registration and Dues

A 21st Century Innovation Takes Hold

Following a successful pilot for August's field trip, NCGS is converting from last century's check-based system for membership renewal, field trip registration, and dinner meeting registration, to an electronic system. The system is hosted by RegFox, which is a fee-per-use system, with no software or internet costs to the NCGS. The fees per registration, which are 2.99% + $0.99 per registration (or $1.71, $2.49, or $3.24 for 1, 2, and 3-year registrations, respectively), will be covered by the NCGS.

To cover these new fees and increased costs for hall-rental, mailings, web-hosting, and insurance, the board approved an increase in dues beginning September 1st to $25 annually for membership and $25/annually for surcharge for paper mailing.

All registrations will be accessed via this link: https://NCGS.regfox.com/ncgs-landing. This brings up an electronic version of the legacy NCGS Membership page (see attached figure). This page will always be active and a link to it will be included in the Newsletter and sent annually to members whose renewal date has arrived. Funds received are directly deposited in the NCGS account and membership details are immediately available to the Membership Secretary for recording.

Registration for Field Trips or the Annual Dinner Meeting will be accessed from the tabs above the Membership Renewal form. These tabs will be grayed out when inactive and highlighted when active. The electronic system is particularly effective for these time-sensitive reservations, as trip availability and dinner commitments are instantaneously updated for both organizers and attendees.

Final Note: If you are among those unable to use the electronic registration, you can contact me (Don M.) via mail at 146 Roan Drive, Danville, CA 94526.

Regards,
Don Medwedeff
NCGS Treasurer

WE'RE ON FACEBOOK!

CHECK OUT THE MOST RECENT POST: @NCGEOLSOC

ALSO, VISIT TWITTER @NORCALGEOSOC

NCGS Board Meetings

Board meetings (online for now) are open to all NCGS members. If you'd like to attend, please contact Jim O'Brient at j.obrient @ comcast.net. Board meetings generally are on Saturday mornings in Jan., Apr./May, and Aug./Sep. Upcoming meeting: **Saturday, May 18, 2024 at 9 a.m., by Zoom**.

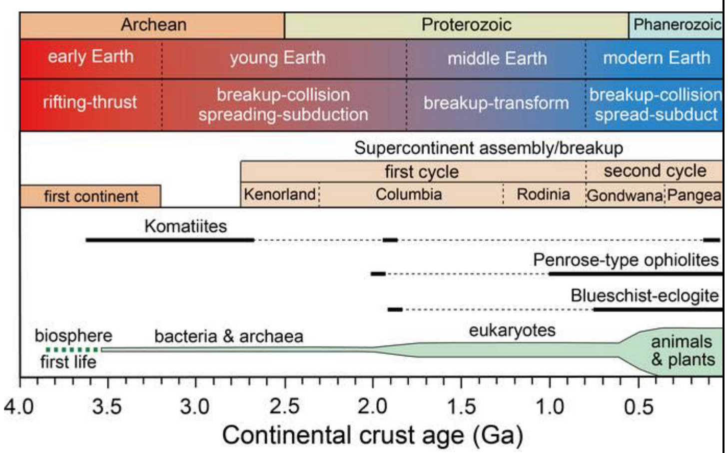
A Great Website to Visit

Dr. Ray Sullivan recently completed an excellent website – see http://raysullivangeologist.com/. As many of you know, Ray was a longtime professor of geology at San Francisco State University as well as serving in multiple positions with other societies and organizations, and with

NCGS as president, program chair, field trip leader and counselor, and co-editor of the Mount Diablo volume recently published with the Geological Society of America. The website has a biography, list of journal and book publications, and a list of projects on which he worked, with some great photos and stories.

Plate Tectonics in the Archean: Observation versus Interpretation

EurekAlert! - January 4, 2024
Source: Science China Press



Ancient plate tectonics in the Archean Period differs from modern plate tectonics in the Phanerozoic Period because of the higher mantle temperatures inside the early Earth, the thicker basaltic crust, and the non-depletion of melt-mobile incompatible trace elements in the mantle. Credit: Science China Press.

The plate tectonics theory established in the 20th century has been successful in interpreting many geological phenomena, processes and events that have occurred in the Phanerozoic. However, the theory has often struggled to provide a coherent framework in interpreting geological records not only in the continental interior but also in the Precambrian period. In the traditional plate tectonics theory dealing with the relationship between plate tectonics and continental geology, continental interior tectonics was often separated from continental margin tectonics in the inheritance and development of their structure and composition. This separation led to the illusion as if the plate tectonics theory were not applicable to Precambrian geology, particularly in interpreting the fundamental geological characteristics of Archean cratons.

This integrated study is presented by Prof. Yong-Fei Zheng at University of Science and Technology of China. It focuses on available observations from Archean geology and inspects their interpretations against the following three characteristic features in the Archean Earth: (1) convective mantle temperatures were as high as 1500-1700°C, (2) newly formed basaltic oceanic crust was as thick as 30-40 km, and (3) the asthenosphere had a composition similar to the primitive mantle rather than the depleted mantle at present. On this basis, the author has successfully applied the plate tectonics theory in the 21st century to interpretation of major geological phenomena on Archean cratons (Fig. 1). The results eliminate the illusion that the Archean continental crust did not originate from a regime of plate tectonics.

Through upgrading the plate tectonics theory from the traditional kinematic model in the 20th century to a holistic kinematic-dynamic model in the 21st century and systematically examining the vertical transport of matter and energy at plate margins, it is evident that plate tectonics can interpret the common geological characteristics of Archean cratons, such as lithological associations, structural patterns, and metamorphic evolution. By deciphering the structure and composition of convergent plate margins as well as their dynamics, the formation and evolution of continental crust since the Archean can be divided into ancient plate tectonics in the Precambrian and modern plate tectonics in the Phanerozoic.

This approach provides a new perspective on and deep insights into the evolution of early Earth and the origin of continental crust. It leads to the development of alternative tectonic models, envisaging vertical movements in the realm of stagnant lid tectonics, including not only bottom-up processes such as mantle plumes and heat pipes but also top-down processes such as lithospheric foundering and subduction. In fact, these vertical processes were not unique to the Archean but persisted into the Phanerozoic. They result from mantle poloidal convection at different depths, not specific to any particular period in Earth's history.

Furthermore, Archean tonalite-trondhjemite-granodiorite (TTG) rocks would result from partial melting of the over-thick basaltic oceanic crust at convergent plate margins. The structural patterns of gneissic domes and greenstone keels would result from the buoyancy-driven emplacement of TTG magmas and its interaction with the basaltic crust at fossil convergent margins, and komatiites in greenstone belts would be the product of mantle plume activity in the regime of ancient plate tectonics. The widespread distribution of high-grade metamorphic rocks in a planar fashion, rather than in zones, is ascribed to separation of the gneissic domes from the greenstone belts.

In addition, volcanic associations in the Archean are short of calc-alkaline andesites, suggesting a shortage of sediment accretionary wedges derived from weathering of granitic continental crust above oceanic subduction zones. Penrose-type ophiolites are absent in Archean igneous associations, which can be ascribed to the formation of basalt accretionary wedges during the subduction initiation of microplates when only the upper volcanic rocks of mid-ocean ridges were off-scraped from the incipiently subducting slab. The absence of blueschist and eclogite as well as classic paired metamorphic belts suggests that convergent plate margins were over-thickened through either warm subduction or hard collision of the thick oceanic crust at moderate geothermal gradients. Therefore, only by correctly recognizing and understanding the nature of Archean cratons can plate tectonics reasonably interpret their fundamental geological characteristics.

As soon as the upgraded version of plate tectonic theory in the 21st century is integrated with the three characteristic features of Archean Earth, it can make revolutionary progress in resolving the previous challenges to interpretations of Archean continental geology. Therefore, this article provides robust arguments for deciphering the inheritance and development relationships between ancient and modern plate tectonic regimes. The results not only contribute to the origin and evolution of continental crust on early Earth, but also shed light on the geodynamic mechanism of how early Earth evolved from stagnant lid tectonics to mobile lid tectonics.

Journal reference: Zheng Y-F., 2024. **Plate tectonics in the Archean: Observations versus interpretations**. *Science China Earth Sciences*, 67(1): 1-30. DOI: 10.1007/s11430-023-1210-5.

Editor's Note: We appreciate this contribution from Bill Motzer, Ph.D., an accomplished geochemist and longtime NCGS member.

Only at Oklo?

(Part 2)
by
Bill Motzer

Background:

The movie Oppenheimer just won the Golden Globes Best Picture for 2023. It had a brief scene about Chicago Pile-1 or CP-1 what was then believed to be the world's first self-sustained nuclear chain reaction. In Part 1 (November 2023 NCGS Newsletter) I described the story behind CP-1's nuclear reaction, which occurred on December 2, 1942, assembled under supervision of physicist Enrico Fermi.

Almost 30 years later, in May 1972, a routine mass spectrometry analysis of uranium hexafluoride (UF_6) showed a discrepancy in the amount of uranium-235 (^{235}U) isotope contained in analyzed samples at the French Pierrelatte Uranium Enrichment Facility. Normally, uranium ore's ^{235}U concentration is 0.7202%, but these samples contained only 0.600%. Concern over this discrepancy resulted in an investigation team led by French physicist Francis Perrin who tracked the depleted uranium's source back to the Oklo Mine, in Gabon, Central Africa (Figure 1-2). Sampling and analyses of different ores resulted in discovery of the Oklo Fossil Reactors confirming that nature had indeed beat humans to a sustained nuclear fission reaction by about 1.8 billion years. (Note: this is an updated version that appeared in the American Chemical Society, California Section newsletter: *The Vortex* (Motzer, 2016).

Predictions:

Perrin, however, was not the first scientist to suggest and determine this phenomenon and his team was aided in part by a 1953 paper published by geochemist George W. Wetherill, professor of geophysics and geology of the University of California at Los Angeles and physicist Mark G. Inghram of the University of Chicago. They postulated that some past uranium deposits could have operated as natural analogs of modern nuclear fission reactors that were then under construction.

In 1956, Paul K. Kuroda, a University of Arkansas nuclear chemist, calculated requirements for such a fossil uranium ore body to have initiated and maintained a self-sustaining fission reaction:

(1) The uranium deposit's size should exceed the average length that fission-inducing neutrons travel; this is approximately 0.67 meters, ensuring that neutrons from one fissioning nucleus are absorbed by another before escaping from the uranium layer or seam.

(2) In the following table, Kuroda showed that ^{235}U must occur in sufficient abundance for a natural fission reaction to occur.

Geological Time, million years before present [Ma]	0 (present)	700	1,000	1,400	2,100	2,800
^{235}U enrichment (percent)	0.7	1.3	1.6	2.3	4.0	7.0

Today's uranium has only 0.72% ^{235}U, which has half-life of about 700 million years and ^{238}U has half-life of about 4.5 billion years. Therefore, ^{235}U decays approximately six times faster than ^{238}U, indicating that the fissile fraction was much higher 1.8 billion years ago (Ga). When Oklo's uranium was deposited, ^{235}U constituted about 3%, which is the approximate amount required for artificially enriched uranium used in most nuclear power plants (Figure 2-2).

(3) A neutron "moderator" should be present. This is a substance slowing neutrons emitted when the uranium nucleus splits allowing or inducing other uranium nuclei to split. In the past ordinary water could be such a moderator. For today's reactors, it's possible to sustain a nuclear reaction using a one percent density, but special

artificial moderator conditions (i.e., deuterated or heavy water) are required.

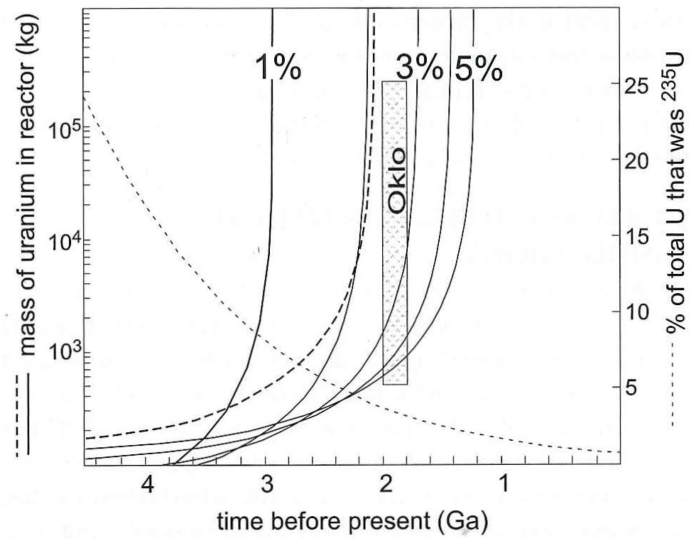
(4) Finally, there should be no "poisons" present that would inhibit nuclear fission reactions. These include substances with large neutron-capture cross sections such as naturally occurring boron, lithium, or other neutron absorbents that would rapidly halt nuclear reactions.

Occurrence:

The above conditions actually prevailed about 1.7 to 1.8 Ga in three uranium deposits at 16 separate natural reactor areas within the Oklo and adjacent Okelobondo uranium mines. These reactors ran for a few hundred thousand years, averaging about 100 kW per day of thermal power during their operating time with a total output of perhaps 15,000 MW-yrs. But Oklo is currently the only known location for this phenomenon and older uranium deposits (e.g., 2.8 Ga) that had higher ^{235}U concentrations (e.g. 7.0%) may exist that could also have been natural reactors. So why haven't these been found? The reasons that they have not been discovered lies in the unique circumstances that occurred only at 1.8 billion years in the past and I'll explore these in future articles.

Figure 1-2: Location Map for the Oklo Uranium Deposit in Gabon, Central Africa. (Source: Meshik, 2005.)

Figure 2-2 (below): Model curves of uranium-235 (^{235}U) critical mass for a natural fission reactor (right axis) versus time (lower axis) is denoted by the thin dashed line showing relative proportions of fissogenic ^{235}U. The U required for a critical natural reactor is shown as a function of age for different uraninite (UO_2) concentrations in the reactor's core (1 to 5 modal percent shown as solid lines) assuming that such a natural reactor composition is quartz (SiO_2), UO_2, and water. Thick dashed line indicates uranium mass increase required at any given time by 10% ilmenite ($FeTiO_3$) added to the mostly UO_2-rich reactor core (5%) because Fe and Ti inhibit or absorb neutrons (i.e., neutron poisons). Although the exact uranium mass required for a natural fission reactor depends on uncertain compositional and geometric factors, it's apparent that the U mass (left axis) required during much of the Archean (4 to 2.5 Ga) was very small (<1,000 kg, or ~0.1 m^3) but increased nearly exponentially as ^{235}U abundances decreased at some time around the Archean-Proterozoic boundary (2.5 Ga). (Source: Coogan and Cullen, 2009.)



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Meshik, A. P., 2005, The Workings of an Ancient Nuclear Reactor: *Scientific American*, v. 293, n. 5, pp.82–89, Bibcode:2005SciAm.293e..82M. doi: 10.1038/scientificamerican1105-82. PMID 16318030.

Motzer, W.E., 2016, Only at Oklo? – Part 2: *The Vortex*, v. LXXVIII, n. 10, pp. 6-7, www.calacs.org.

Wetherill, G.W., 1953, Spontaneous Fission Yields from Uranium and Thorium: *Physical Review*. v. 92, p. 907.

Following Diz Swift's excellent presentation to NCGS in October, Colin Whitfield forwarded a note regarding an article on funding flowing to startups in the carbon removal space, which may be of interest to the our NCGS readership. The link is https://news.crunchbase.com/clean-tech-and-energy/carbon-removal-storage-startup-funding-2023/. NCGS, as a nonprofit, does not endorse any specific investments and provides this article and link as follow-up for those interested in getting more information on a very important topic. The article follows below.

From Buildings to Ocean Water, Startups Are Finding More Places to Stow Carbon

Source: *Crunchbase News*, October 24, 2023
By Joanna Glasner

There is too much carbon in the atmosphere, and we have to find somewhere else to put it. Preferably, somewhere stable and contained. Maybe deep underground. Potentially in some concrete. Or perhaps sucked into the vastness of the ocean.

Looking at funded startups in the carbon removal space, such ideas aren't abstractions. Rather, they describe several business models around carbon removal that have collectively pulled in hundreds of millions of dollars from investors this year alone.

Funding records show that financing around carbon removal themes have accelerated in recent quarters, in tandem with climate data pointing to increasingly dire impacts should atmospheric carbon levels continue to rise. To some extent, it's a recognition that, given the suboptimal adoption pace of clean energy sources, there's an urgent need for other options.

"The thesis is we're not going to transition fast enough," said Peter Relan, a seed investor who recently launched a climate-tech incubator focused on carbon management. Its early investments include Equatic, a developer of technology that uses seawater to remove carbon dioxide from the atmosphere and produce green hydrogen.

Using Crunchbase data, we assembled a list of 13 companies touting intriguing carbon removal strategies:

Carbon Removal-Focused Funded Companies

Organization Name	Description	Total Equity Funding Amount (US Dollars)
Svante	Carbon capture and removal solutions	$476,638,547
Loam Bio	Agtech company uses microbes to help the carbon cycle	$110,152,752
Charm Industrial	Puts oil back underground via bio-oil sequestration and industrial syngas production.	$100,000,000
Carbon Cure Technol	Creates, develops, and licenses solutions that consume waste CO_2 to make better concrete.	$89,292,804
Brimstone Energy	Hardware cleantech startup aims to reduce CO_2 emissions using innovative technologies.	$55,000,000
Ebb Carbon	Works on reverse electrochemical ocean deacidification process that captures CO_2 from the atmosphere.	$23,000,000
Captura	Works on a globally scalable carbon capture system to support a sustainable future for the climate.	$12,000,000
Undo	Carbon removal company specializing in enhanced rock weathering.	$11,936,587
Carbon-Built	Enables concrete manufacturing to drive greenhouse gas reductions through the utilization of CO_2 and other industrial wastes.	$10,000,000
Carbon-aide	Provides technology to utilize and store carbon dioxide in the precast concrete industry.	$1,950,993
EcoLocked	Turns buildings into carbon sinks; helps the construction industry build with climate-neutral concrete while optimizing performance.	$1,769,661
Carbfix	Provides natural, permanent storage solution by turning CO_2 into stone underground in less than two years.	--
Equatic	Catalyzes and powers the green economy.	--

Below, we look at some of the places where startups are planning to put all that carbon:

The ocean: Several startups are working on technologies and processes to store excess carbon in the ocean.

One of the more heavily funded is San Carlos, California-based Ebb Carbon, which proclaims that "the ocean is one of the largest carbon sinks on the planet." The company landed a $20 million Series A in April around its stated mission to "remove gigatons of CO_2 from the air while reducing ocean acidification."

Another, Pasadena, California-based Captura, has raised $12 million to use a process known as direct ocean capture to remove and capture oceanic CO_2. The process reportedly leaves a layer of decarbonized ocean water that will then react with the atmosphere to draw down an equivalent quantity of carbon dioxide.

The aforementioned Equatic, meanwhile, has secured seed funding for the rollout of its seawater electrolysis technology.

Soil: Another place to put carbon is in soil. This is the solution proposed by Loam Bio, an Australian startup that landed a $67 million Series B in February. The company says its technology "helps plants take CO_2 from the atmosphere and transform it into the most stable forms of soil carbon, turning the world's croplands into giant carbon sinks."

U.K.-based Undo also has its eyes on farmland, albeit with a rockier approach. The company uses a process called enhanced rock weathering to lock away carbon, producing a basalt rock it says can deliver nutrients to farm soil.

Deep underground: When it comes to storing carbon, perhaps deeper is better. To this end, San Francisco-based Charm Industrial picked up $100 million in Series B funding this summer for its plan to "put oil back underground." The startup uses plants to capture carbon dioxide. It then converts biomass into a "stable, carbon-rich liquid" that it can then pump deep underground.

Burnaby, British Columbia-based Svante, the most heavily funded company on our list, is more broadly focused on making filters and machines that capture and remove CO_2 from industrial emissions and the air. However, it also has an underground storage angle, stating on its website that "the CO_2 we capture is concentrated to pipeline grade purity, which can be safely transported and stored underground or used to make other products."

Carbfix, an Icelandic startup, has raised $117 million in grant-supported funding for what it describes as a permanent storage solution capable of "turning CO_2 into stone underground in less than two years." Partners include Climeworks, a heavily funded Swiss direct air capture provider that works with Carbfix to store carbon.

Concrete and buildings: Our human-made environments of buildings and pavement are well-known for absorbing heat. But startups are betting that in the future we can do a better job producing materials and structures that actually help remove atmospheric carbon.

A couple months ago, we wrote about the robust funding environment for clean concrete. Among startups in the space, several are looking at ways to store carbon dioxide in concrete or remove atmospheric carbon in the production process.

The biggest round was a recent one: Dartmouth, Nova Scotia-based CarbonCure Technologies landed $80 million in July for carbon removal technologies that introduce recycled CO_2 into fresh concrete to reduce its carbon footprint.

Next is Brimstone Energy, a Berkeley, California-based company that raised $55 million last year to scale the making of "carbon-negative cement" through a process it says removes carbon dioxide from the air.

There's also some dealmaking at the seed stage. Berlin-based EcoLocked secured initial funding last year to develop sustainable building materials by integrating biocarbon, with a stated goal to "turn buildings into carbon sinks." Another seed startup, Finland-based Carbonaide, says it is working on ways to "turn concrete from a large emission source into a carbon sink."

Will it work?

Of course, technology-driven approaches aren't the only way to remove CO_2 from the atmosphere. Plants, for example, have been doing this for over 400 million years without any help from venture capitalists.

Today, however, analyses of pathways to limit global warming to 1.5°C generally incorporate human-led efforts at carbon dioxide removal, per an IPCC report. That said, authors also observed that "CDR deployed at scale is unproven, and reliance on such technology is a major risk."

Still, the sums of money going into innovative approaches to stowing away carbon indicate investors believe these could turn into massively scalable businesses.

A couple big M&A deals in an adjacent space also show potential for returns.

In July, ExxonMobil announced plans to acquire Denbury Inc., a publicly traded developer of carbon capture, utilization and storage infrastructure, in a stock transaction valued then at a whopping $4.9 billion.

A month later, Occidental Petroleum agreed to pay $1.1 billion for Squamish, British Columbia-based Carbon Engineering, a developer of direct air capture technology that previously raised over $110 million in venture, strategic and grant funding.

Notably, these [last two] are acquirers better known for pulling fossil fuels out of the ground. But in an exceedingly slow M&A environment, it's still significant that carbon capture and removal is one of a few areas where buyers are willing to spend big.

Scientists zero in on timing, causes of ice age mammal extinctions in southern California

ScienceDaily, August 18, 2023
Source: Texas A&M University

The end of the last Ice Age also marked the end for more than three dozen genera of large mammals in North America, from mammoths and mastodons to bison and saber-toothed cats. Details concerning the precise timing and circumstances, however, have remained murky ever since.

A team of scientists that included Texas A&M University archaeologist Dr. Michael Waters recently focused on the well-known Rancho La Brea Tar Pits in southern California in their quest to provide answers to these questions, resulting in the most exact and detailed timeline for the extinctions that happened during the latter part of the Pleistocene period in North America, along with some foreboding insight into the area's present and future. Their work is featured on the cover of a recent issue of *Science*.

Waters, a distinguished professor in the Department of Anthropology and director of the Center for the Study of the First Americans (CSFA), along with roughly a dozen fellow researchers, examined the timing and cause of the extinction of a variety of large mammals, known as megafauna, that got stuck in tar at Rancho La Brea, ensuring the preservation of their bones. The team used the radiocarbon dating method to date 169 bones from seven different animals -- bison, horse, camel and ground sloths as well as the carnivores that ate them, including the saber-toothed cat, dire wolf and American lion. They also compared those findings to regional pollen and charcoal records along with continent-wide data on human and large mammal populations.

Armed with their new data, the researchers subsequently used time-series modeling to produce the most detailed chronobiology to date, showing the relationships between climate and vegetation change, fire activity, human demographics and megafauna extinctions -- groundbreaking results they report in the Aug. 18 edition of the world-leading academic journal.

Waters says the team's findings reveal that Ice Age mammal populations in southern California were steady from 15,000 to around 13,250 years ago. Afterward, there was a sharp decline in the population of the seven animals studied, and they all became extinct between 13,070 to 12,900 years ago.

In an interesting modern-day parallel, this extinction event corresponds with a change in the environment from 13,300 to 12,900 years ago marked by warming and drying that made the land more vulnerable to fires in southern California. Charcoal records show that fires increased around 13,500 years ago and peaked between 13,200 and 12,900 years ago. Studies show that humans arrived in North America's Pacific coast 16,000 to 15,000 years ago and lived alongside the megafauna for 2,000 to 3,000 years before their extinction.

While humans hunted animals during this period, Waters says the impact of hunting on the demise of the megafauna likely was minor because of the low population of humans on the landscape. However, the fires would have been devastating, resulting in the loss of habitat causing the rapid decline and extinction of the megafauna in southern California. The study suggests these fires were ignited by humans, which had increased in number by that time.

"Fire is a way that small numbers of humans can have a large impact over a broad area," said Waters, who also cautions that climate changes observed in present-day California are similar to those of the late Pleistocene. "This study has implications for the changes we see in southern California today," Waters added. "The temperatures are rising, and the area is drying. We also see a dramatic increase in fires. It appears that history may be repeating itself."

While Waters acknowledges that this is the story of extinction at Rancho La Brea, he says it has the potential to offer insights into when extinctions happened across all of North America. "Mammoths and mastodons survived in many parts of North America until around 12,700 years ago," he added. "These animals were hunted by the Clovis people between about 13,000 and 12,700 years ago. We are now dating megafauna remains from other locations to give a broader understanding of the Rancho La Brea research in the context of North America."

The museum at La Brea Tar Pits holds the world's largest collection of fossils from the Ice Age and has been central to the study of animal and plant life at the end of the Pleistocene epoch for more than a century. Its naturally occurring asphalt pools entrapped and preserved the bones of thousands of individual animals representing dozens of megafaunal species during the last 60,000 years, enabling scientists to determine when different species disappeared from the ecosystem and why.

The team's research was supported by the National Science Foundation and various Texas A&M-specific grants, such as the CSFA and the North Star Archaeological Research Fund.

Journal Reference: F. Robin O'Keefe et al. **Pre–Younger Dryas megafaunal extirpation at Rancho La Brea linked to fire-driven state shift**. *Science*, 2023 DOI: 10.1126/science.abo3594.

Science and technology | Ground truths

Could AI help find valuable mineral deposits?

Computers have keener eyes than geologists

Source: The Economist, November 4, 2023
From Berkeley, California and Boston, Massachusetts

The future is electric. That means it will need a lot of batteries, motors and wires. That, in turn, means a lot of cobalt, copper, lithium and nickel with which to build them. Great times, then, for prospectors, and particularly for any who think they can increase the efficiency of their profession. Several firms are applying artificial intelligence (AI) to the process, both to improve the odds of surface strikes and to detect underground ore bodies that are invisible to current techniques.

KoBold Metals in Berkeley, California, Earth AI in San Francisco and VerAI in Boston are tiddlers at the moment, as are SensOre, in Melbourne and OreFox, in Brisbane. But at least one bigger fish—Rio Tinto, an Australian-British firm—is also keen. They are garnering reams of geological, geochemical and geophysical data to feed to software models. These, they hope, will spot patterns and draw inferences about where to sink new mines.

Some of the data are new. But a lot once mouldered in the archives of national geological surveys, journals of geology and other historical repositories—or, in the case of Rio Tinto, which has been operating for 150 years, sat in the form of rock cores in various sheds around the world.

Kobolds were mythical underground sprites that bedeviled miners in medieval Germany. (They also gave their name to cobalt.) Kurt House, KoBold's boss, hopes some of their magic will rub off. His firm has reformatted archive data from around the world, many of which are on paper and some of which go back to the 19th century, into machine-useable form. That has permitted it to build maps of areas of interest all over Earth's surface.

Some of those maps are used to train the company's AI models. Others are used to test that software's effectiveness by checking how good it is at predicting known ore deposits on maps it has not previously seen. If it passes, it can be let loose on under-explored places of interest, generating leads for KoBold's geologists.

Earth AI, led by Roman Teslyuk, SensOre, led by Richard Taylor, and OreFox, led by Warwick Anderson, have taken similar approaches, but have concentrated on Australia, which has particularly rich public geological records. VerAI, led by Yair Frastai, focuses on the western bits of North and South America, home to eight of the world's ten biggest copper mines.

Dr House is especially proud of his AI's ability to predict the shapes and distributions of subterranean plutonic intrusions. These are bodies of igneous rock, often ore-bearing, that have risen as liquid magma from Earth's interior but solidified before they reached the surface. They can be detected from the surface via magnetic anomalies which suggest that a particular group of rocks formed at a different time from its surroundings, a standard practice in the industry. But KoBold's AI is able to make more accurate predictions of the shapes of these intrusions, and so suggest the most effective places to drill.

And with success. Last year, KoBold announced its discovery of a rich deposit of chalcocite, a sulfide of copper, in Zambia. Earth AI, meanwhile, has to its credit a big find of molybdenum (an important component of specialist steels) in New South Wales. VerAI has found ore containing copper, gold and silver in Chile and Peru. SensOre has found a large source of lithium in Western Australia. And OreFox's technology has turned up a potential gold mine in Victoria, plus several promising copper prospects.

Rio Tinto is building what Russell Eley, its head of exploration data science, calls a "virtual core shed". This will bring together details of the many rock-core samples the firm has collected over the years. Software will then search these for patterns that will assist the interpretation of new cores, and tell geologists the best places to drill next.

Dr House observes that 99% of exploration projects fail to turn into actual mines. AI therefore has plenty of room to improve things. It may also help with a more subtle problem. By greatly expanding the volume of rock which can be searched, it will enable new strikes in familiar, well-governed countries, lessening the need to rely on what Mr Taylor diplomatically calls "exotic jurisdictions" for future supplies. ■

This article appeared in the Science & Technology section of the Economist's print edition under the headline "Ground truths."

Study uncovers potential origins of life in ancient hot springs

Newcastle University research turns to ancient hot springs to explore the origins of life on Earth.

ScienceDaily, January 12, 2024
Source: Newcastle University

The research team, funded by the UK's Natural Environmental Research Council, investigated how the emergence of the first living systems from inert geological materials happened on the Earth, more than 3.5 billion years ago. Scientists at Newcastle University found that by mixing hydrogen, bicarbonate, and iron-rich magnetite under conditions mimicking relatively mild hydrothermal vent results in the formation of a spectrum of organic molecules, most notably including fatty acids stretching up to 18 carbon atoms in length.

Published in the journal *Communications Earth & Environment*, their findings potentially reveal how some key molecules needed to produce life are made from inorganic chemicals, which is essential to understanding a key step in how life formed on the Earth billions of years ago. Their results may provide a plausible genesis of the organic molecules that form ancient cell membranes, that were perhaps selectively chosen by early biochemical processes on primordial Earth.

Fatty acids in the early stages of life

Fatty acids are long organic molecules that have regions that both attract and repel water that will automatically form cell-like compartments in water naturally and it is these types of molecules that could have made the first cell membranes. Yet, despite their importance, it was uncertain where these fatty acids came from in the early stages of life. One idea is that they might have formed in the hydrothermal vents where hot water, mixed with hydrogen-rich fluids coming from underwater vents mixed with seawater containing CO_2.

The group replicated crucial aspects of the chemical environment found in early Earth's oceans and the mixing of the hot alkaline water from around certain types of hydrothermal vents in their laboratory. They found that when hot hydrogen-rich fluids were mixed with carbon dioxide-rich water in the presence of iron-based minerals that were present on the early Earth it created the types of molecules needed to form primitive cell membranes.

Lead author, Dr Graham Purvis, conducted the study at Newcastle University and is currently a Postdoctoral Research Associate at Durham University. He said: "Central to life's inception are cellular compartments, crucial for isolating internal chemistry from the external environment. These compartments were instrumental in fostering life-sustaining reactions by concentrating chemicals and facilitating energy production, potentially serving as the cornerstone of life's earliest moments.

The results suggest that the convergence of hydrogen-rich fluids from alkaline hydrothermal vents with bicarbonate-rich waters on iron-based minerals could have precipitated the rudimentary membranes of early cells at the very beginning of life. This process might have engendered a diversity of membrane types, some potentially serving as life's cradle when life first started.

Moreover, this transformative process might have contributed to the genesis of specific acids found in the elemental composition of meteorites."

Principal Investigator Dr Jon Telling, Reader in Biogeochemistry, at School of Natural Environmental Sciences, added: "We think that this research may provide the first step in how life originated on our planet. Research in our laboratory now continues on determining the second key step; how these organic molecules which are initially 'stuck' to the mineral surfaces can lift off to form spherical membrane-bounded cell-like compartments; the first potential 'protocells' that went on to form the first cellular life."

Intriguingly, the researchers also suggest that membrane-creating reactions similar reactions, could still be happening in the oceans under the surfaces of icy moons in our solar system today. This raises the possibility of alternative life origins in these distant worlds.

Journal Reference: Graham Purvis, Lidija Šiller, Archie Crosskey, Jupiter Vincent, Corinne Wills, Jake Sheriff, Cijo Xavier, Jon Telling. **Generation of long-chain fatty acids by hydrogen-driven bicarbonate reduction in ancient alkaline hydrothermal vents**. *Communications Earth & Environment*, 2024; 5 (1) DOI: 10.1038/s43247-023-01196-4.

Separating out signals recorded at the seafloor

Research shows that variations in pyrite sulfur isotopes may not represent the global processes that have made them such popular targets of analysis and interpretation. A new microanalysis approach helps to separate out signals that reveal the relative influence of microbes and that of local climate.

ScienceDaily, November 24, 2023
Source: Washington University in St. Louis

Blame it on plate tectonics. The deep ocean is never preserved, but instead is lost to time as the seafloor is subducted. Geologists are mostly left with shallower rocks from closer to the shoreline to inform their studies of Earth history.

"We have only a good record of the deep ocean for the last ~180 million years," said David Fike, the Glassberg/Greensfelder Distinguished University Professor of Earth, Environmental, and Planetary Sciences in Arts & Sciences at Washington University in St. Louis. "Everything else is just shallow-water deposits. So it's really important to understand the bias that might be present when we look at shallow-water deposits."

One of the ways that scientists like Fike use deposits from the seafloor is to reconstruct timelines of past ecological and environmental change. Researchers are keenly interested in how and when oxygen began to build up in the oceans and atmosphere, making Earth more hospitable to life as we know it.

For decades they have relied on pyrite, the iron-sulfide mineral known as "fool's gold," as a sensitive recorder of conditions in the marine environment where it is formed. By measuring the bulk isotopic composition of sulfur in pyrite samples -- the relative abundance of sulfur atoms with slightly different mass -- scientists have tried to better understand ancient microbial activity and interpret global chemical cycles.

But the outlook for pyrite is not so shiny anymore. In a pair of companion papers published Nov. 24 in the journal *Science*, Fike and his collaborators show that variations in pyrite sulfur isotopes may not represent the global processes that have made them such popular targets of analysis.

Instead, Fike's research demonstrates that pyrite responds predominantly to local processes that should not be taken as representative of the whole ocean. A new microanalysis approach developed at Washington University helped the researchers to separate out signals in pyrite that reveal the relative influence of microbes and that of local climate.

For the first study, Fike worked with Roger Bryant, who completed his graduate studies at Washington University, to examine the grain-level distribution of pyrite sulfur isotope compositions in a sample of recent glacial-interglacial sediments. They developed and used a cutting-edge analytical technique with the secondary-ion mass spectrometer (SIMS) in Fike's laboratory.

"We analyzed every individual pyrite crystal that we could find and got isotopic values for each one," Fike said. By considering the distribution of results from individual grains, rather than the average (or bulk) results, the scientists showed that it is possible to tease apart the role of the physical properties of the depositional environment, like the sedimentation rate and the porosity of the sediments, from the microbial activity in the seabed.

"We found that even when bulk pyrite sulfur isotopes changed a lot between glacials and interglacials, the minima of our single grain pyrite distributions remained broadly constant," Bryant said. "This told us that microbial activity did not drive the changes in bulk pyrite sulfur isotopes and refuted one of our major hypotheses."

"Using this framework, we're able to go in and look at the separate roles of microbes and sediments in driving the signals," Fike said. "That to me represents a huge step forward in being able to interpret what is recorded in these signals."

In the second paper, led by Itay Halevy of the Weizmann Institute of Science and co-authored by Fike and Bryant, the scientists developed and explored a computer model of marine sediments, complete with mathematical representations of the microorganisms that degrade organic matter and turn sulfate into sulfide and the processes that trap that sulfide in pyrite.

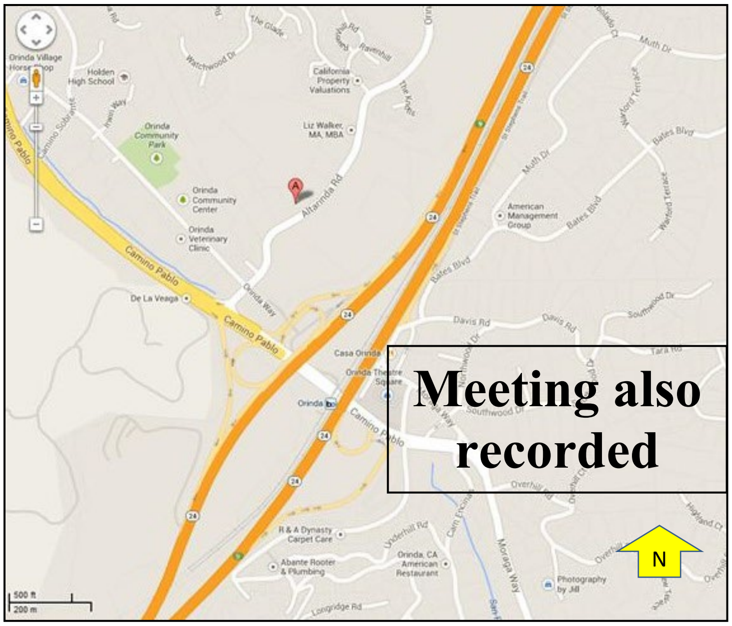
"We found that variations in the isotopic composition of pyrite are mostly a function of the depositional environment in which the pyrite formed," Halevy said. The new model shows that a range of parameters of the sedimentary environment affect the balance between sulfate and sulfide consumption and resupply, and that this balance is the major determinant of the sulfur isotope composition of pyrite.

"The rate of sediment deposition on the seafloor, the proportion of organic matter in that sediment, the proportion of reactive iron particles, the density of packing of the sediment as it settles to the seafloor -- all of these properties affect the isotopic composition of pyrite in ways that we can now understand," he said.

Importantly, none of these properties of the sedimentary environment are strongly linked to the global sulfur cycle, to the oxidation state of the global ocean, or essentially any other property that researchers have traditionally used pyrite sulfur isotopes to reconstruct, the scientists said.

"The really exciting aspect of this new work is that it gives us a predictive model for how we think other pyrite records should behave," Fike said. "For example, if we can interpret other records -- and better understand that they are driven by things like local changes in sedimentation, rather than global parameters about ocean oxygen state or microbial activity -- then we can try to use this data to refine our understanding of sea level change in the past."

Journal Reference: R. N. Bryant, J. L. Houghton, C. Jones, V. Pasquier, I. Halevy, D. A. Fike. **Deconvolving microbial and environmental controls on marine sedimentary pyrite sulfur isotope ratios**. *Science*, 2023; 382 (6673): 912. DOI: 10.1126/science.adg6103.



optimization, data assimilation and machine learning. He has many years of research experience in the oil and gas industry working for Chevron and Schlumberger prior to Tachyus. He has received many awards including the INFORMS Prize, the Dantzig Dissertation award from INFORMS, Miller and Ramey Fellowships at Stanford University, Chevron's Excellence in Reservoir Management award, and a SIAM award for excellence in research. He holds a Ph.D. in Petroleum Engg., a Ph.D. Minor in Operations Research from Stanford University and a B.Tech from Indian School of Mines. He is a SPE Distinguished Lecturer and serves on the committees of the SPE Reservoir Simulation Conference, the EAGE European Conference on the Mathematics of Oil Recovery and the JPT editorial committee.

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