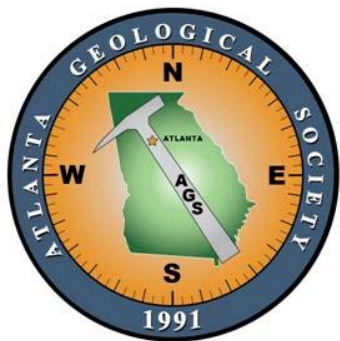




Atlanta Geological Society Newsletter

ODDS AND ENDS

Dear AGS members,

More than 10 years ago I decided to never take a trip where I don't work in some geological exploring. Not every trip is as geologically fulfilling as a trip to a geologic conference in Idaho. We are wrapping up a trip to the Williamsburg/Virginia Beach area. Lots of history but the geology has been hard to find. Landing by ship (ferry) in Jamestown was fun. I did find a peddle powered quartzite sharper in Colonial Williamsburg.



A dolphin cruise did take us up past Cape Henry and the entrance to the Chesapeake Bay. Certainly the Ice Age sea level fluctuation created all the rivers and bays of this tidewater area but you can't actually see the geology. Then, while washing my feet off after a trip to the beach, there it was! The hose spray washed away the quartz leaving behind the black magnetite. Ah, sedimentology to the rescue. Now my vacation is complete.

May Meeting

Join us **Tuesday, May 30, 2017** at the Fernbank Museum of Natural History, 760 Clifton Road NE, Atlanta GA. The social starts at 6:30 p.m. and the meeting starts approximately 7 p.m.

This month's presentation is: **Piecing Together a Picture of Community Responses to Glaciation, Human Arrival, and Climate Change at Natural Trap Cave, Northern Wyoming**, presented by Dr. Jenny McGuire. You find more information about Dr. McGuire in her bio on the next page.

Please come out, enjoy a bite to eat, the camaraderie, interesting presentations and perhaps some individual discussions on the importance of accurate mineral, rock and fossil characterizations.

The AGS Web Page is getting a facelift, and is currently under redevelopment

www.atlantageologicalsociety.org

or at Facebook

facebook.com/Atlanta-Geological-Society

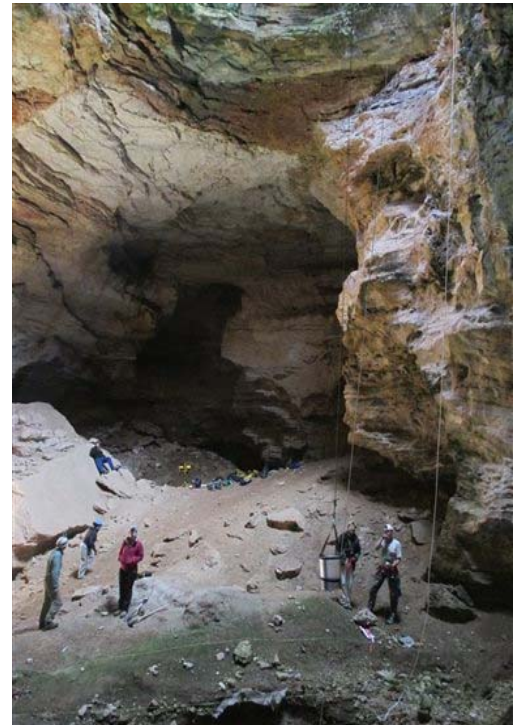
Piecing Together a Picture of Community Responses to Glaciation, Human Arrival, and Climate Change at Natural Trap Cave, Northern Wyoming

Atlanta Geological Society Meeting May 30, 2017

Fernbank Museum of Natural History, Atlanta

Dr. Jenny McGuire, dual majored in Earth & Ocean Sciences and Biological Anthropology & Anatomy at Duke University. After taking some time off to work as a scientist-in-the-park at Zion National Park, she began graduate school at University of California at Berkeley. There, she studied Quaternary paleontology and how species have responded to changing environmental conditions. Since then, she has held postdoctoral positions at the National Evolutionary Synthesis Center in Durham and at the University of Washington. Now she is part of the research faculty at Georgia Tech. Every summer for the last several years, she has participated in excavations at Natural Trap Cave, in the State of Wyoming, this site holds the historic records of the dynamic changes that have occurred in mammal communities dating back 150,000 years ago.

In the summer of 2014, a team led by Julie Meachen and Alan Cooper reopened Natural Trap Cave, a 25-meter deep sinkhole at the base of the Bighorn Mountains in Big Horn County, Wyoming. Natural Trap Cave contains an abundant and diverse vertebrate assemblage. Radiocarbon dates coupled with fine-scaled stratigraphy indicate that we will have the resolution to distinguish major late Pleistocene and early Holocene events, including the transition from the Last Glacial Maximum to the current interglacial, end-Pleistocene extinctions, and the Holocene Climatic Optimum. I will tell you how we are combining isotopic, radiocarbon, stratigraphic, plant, and vertebrate data to create a picture of how communities responded to each of these events.



This Month's Atlanta Geological Society Sponsor



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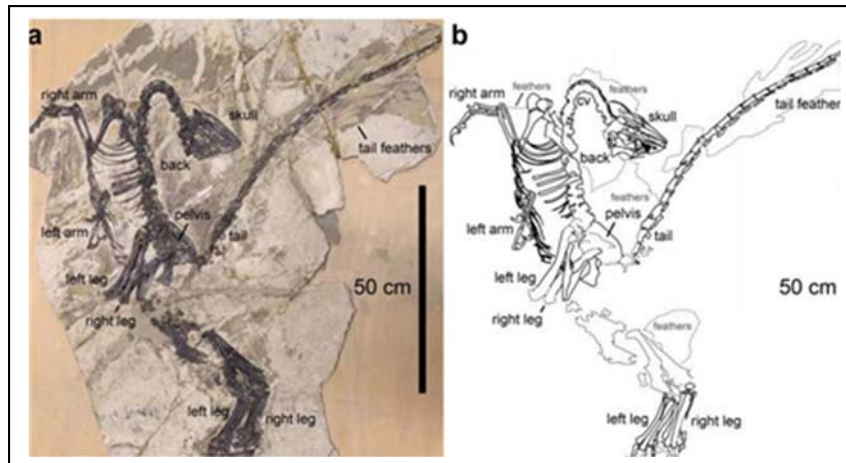
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New Species of Troodontid with Asymmetric Feathers Found in China

Abstract

Asymmetrical feathers have been associated with flight capability but are also found in species that do not fly, and their appearance was a major event in feather evolution. Among non-avian theropods, they are only known in microraptorine dromaeosaurids. Here we report a new troodontid, *Jianianhualong tengi* gen. et sp. nov., from the Lower Cretaceous Jehol Group of China, that has anatomical features that are transitional between long-armed basal troodontids and derived short-armed ones, shedding new light on troodontid character evolution. It indicates that troodontid feathering is similar to *Archaeopteryx* in having large arm and leg feathers as well as frond-like tail feathering, confirming that these feathering characteristics were widely present among basal paravians. Most significantly, the taxon has the earliest known asymmetrical troodontid feathers, suggesting that feather asymmetry was ancestral to Paraves. This taxon also displays a mosaic distribution of characters like *Sinusoasus*, another troodontid with transitional anatomical features.



The asymmetrically feathered troodontid *Jianianhualong tengi* DLXH 1218. (a) Photograph, and (b) line drawing of the fossil specimen. Scale is 50cm. Credit: Xu, Currie, Pittman et al. 2017.

A team of researchers from Hong Kong, China and Canada has identified a new species of Chinese troodontid—an ancient species that sported asymmetric feathers. In their paper published in the journal *Nature Communications*, the team describes the specimen, which has been likened to a giant chicken with teeth, and why they believe the find extends the emergence of a certain trait further back in time.

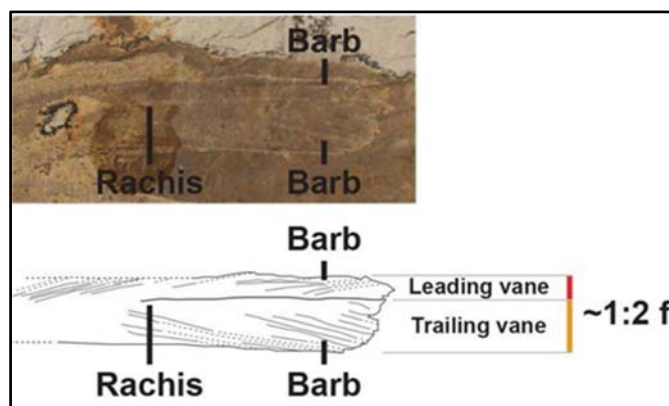
The well-preserved fossilized specimen was found in Liaoning, which is part of an area in China where a lot of other well-preserved fossils have been found in the past. The new species has been dated to approximately 125 million years ago, and has been named *Jianianhualong tengi* its defining quality is its asymmetrical feathers, which prior research has suggested is a feature of birds that are able to fly. The fossil remains showed the bird-like dinosaur to be approximately three feet tall and likely covered in plumage. It also had a mouthful of teeth, unlike modern birds. Though very well preserved, it is still not clear if the creature was actually able to fly.

Evidence at the dig site showed that the specimen had a long tail with asymmetric feathers, and because of that, the researchers suggest it was likely that it had asymmetrical feathers on its arms and legs, as well. The finding also shed some new light on the development of animal flight from bird-like dinosaurs to creatures

New Species of Troodontid with Asymmetric Feathers Found in China (Continued)

that eventually became birds. The specimen has been classified as part of a group called troodontids, which is part of a larger group that also includes birds, both those alive today and those that have gone extinct. The researchers note that the legs and skull of *J. tengi* resemble those of later troodontids, but its pelvis and arms more closely resemble earlier species, suggesting *J. tengi* was, perhaps, a bit of an intermediary on the road toward flight.

The researchers note that what makes the specimen so interesting is both its place in the phylogenetic tree and the asymmetric feathers together, they suggest the species might be a common ancestor of troodontids and birds, which would mean pushing such a link further back in time.



An asymmetrical tail feather from the troodontid *Jianianhualong tengi* DLXH 1218. (a) Photograph, and (b) line drawing of the fossil feather. Scale is 2cm. Credit: Xu, Currie, Pittman et al. 2017.

Read more at: <https://phys.org/news/2017-05-species-troodontid-asymmetric-feathers-china.html#jCp>

3.3 Million-Year-Old Fossil Reveals Origins of the Human Spine

Analysis of a 3.3 million-year-old fossil skeleton reveals the most complete spinal column of any early human relative, including vertebrae, neck and rib cage. The findings, published this week in the *Proceedings of the National Academy of Sciences*, indicate that portions of the human spinal structure that enable efficient walking motions were established millions of years earlier than previously thought.

The fossil, known as "Selam," is a nearly complete skeleton of a 2½ year-old child discovered in Dikika, Ethiopia in 2000 by Zeresenay (Zeray) Alemseged, professor of organismal biology and anatomy at the University of Chicago and senior author of the new study. Selam, which means "peace" in the Ethiopian Amharic language, was an early human relative from the species *Australopithecus afarensis*—the same species as the famous Lucy skeleton.

In the years since Alemseged discovered Selam, he and his lab assistant from Kenya, Christopher Kiarie, have been preparing the delicate fossil at the National Museum of Ethiopia. They slowly chipped away at the sandstone surrounding the skeleton and used advanced imaging tools to further analyze its structure. "Continued and painstaking research on Selam shows that the general structure of the human spinal column emerged over 3.3 million years ago, shedding light on one of the hallmarks of human evolution,"

3.3 Million-Year-Old Fossil Reveals Origins of the Human Spine

(Continued)

Alemseged said. "This type of preservation is unprecedented, particularly in a young individual whose vertebrae are not yet fully fused."



A vertebrae of the Selam skeleton. Credit: Zeray Alemseged, University of Chicago

Many features of the human spinal column and rib cage are shared among primates. But the human spine also reflects our distinctive mode of walking upright on two feet. For instance, humans have fewer rib-bearing vertebrae - bones of the back - than those of our closest primate relatives. Humans also have more vertebrae in the lower back, which allows us to walk effectively. When and how this pattern evolved has been unknown until now because complete sets of vertebrae are rarely preserved in the fossil record.

"For many years we have known of fragmentary remains of early fossil species that suggest that the shift from rib-bearing, or thoracic, vertebrae to lumbar, or lower back, vertebrae was positioned higher in the spinal column than in living humans. But we have not been able to determine how many vertebrae our early ancestors had," said Carol Ward, a Curator's Distinguished Professor of Pathology and Anatomical Sciences in the University of Missouri School of Medicine, and lead author on the study. "Selam has provided us the first glimpse into how our early ancestors' spines were organized."

In order to be analyzed, Selam had to take a trip. She traveled to the European Synchrotron Radiation Facility in Grenoble, France, where Alemseged and the research team used high- resolution imaging technology to visualize the bones.

"This technology provides the opportunity to virtually examine aspects of the vertebrae otherwise unattainable from the original specimen," said coauthor of the study Fred Spoor, a professor of evolutionary anatomy in the Department of Biosciences at the University College London.

The scans indicated that Selam had the distinctive thoracic-to-lumbar joint transition found in other fossil human relatives, but the specimen is the first to show that, like modern humans, our earliest ancestors had only twelve thoracic vertebrae and twelve pairs of ribs. That is fewer than in most apes.

3.3 Million-Year-Old Fossil Reveals Origins of the Human Spine

(Continued)

This configuration marks a transition toward the type of spinal column that allows humans to be the efficient, athletic walkers and runners we are today.

"We are documenting for the first time in the fossil record the emergence of the number of the vertebrae in our history, when the transition happened from the rib-bearing vertebrae to lower back vertebrae, and when we started to extend the waist," Alemseged said. "This structure and its modification through time is one of the key events in the history of human evolution."

Read more at: <https://phys.org/news/2017-05-million-year-old-fossil-reveals-human-spine.html#jCp>

Researchers Discover Hottest Lavas That Erupted in Past 2.5 Billion Years

An international team of researchers led by geoscientists with the Virginia Tech College of Science recently discovered that deep portions of Earth's mantle might be as hot as it was more than 2.5 billion years ago.

The study, led by Esteban Gazel, an assistant professor with Virginia Tech's Department of Geosciences, and his doctoral student Jarek Trela of Deer Park, Illinois, is published in the latest issue of *Nature Geoscience*. The study brings new, unprecedented evidence on the thermal evolution of the deep Earth during the past 2.5 billion years, Gazel said.

The Archean Eon covering from 2.5 to 4 billion years ago is one of the most enigmatic times in the evolution of our planet, Gazel said. During this time period, the temperature of Earth's mantle, the silicate region between the crust and the outer core was hotter than it is today, owing to a higher amount of radioactive heat produced from the decay of elements such as potassium, thorium, and uranium. Because Earth was hotter during this period, this interval of geologic time is marked by the widespread of occurrence of a unique rock known as komatiite.

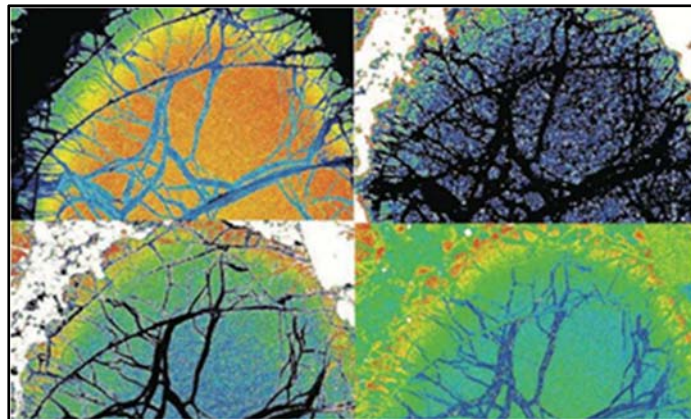
"Komatiites are basically superhot versions of Hawaiian style lava flows,". "You can imagine a Hawaiian lava flow, only komatiites were so hot that they glowed white instead of red, and they flowed on a planetary surface with very different atmospheric conditions, more similar to Venus than the planet we live on today", Gazel said.

Earth essentially stopped producing abundant hot komatiites after the Archean era because the mantle has cooled during the past 4.5 billion years due to convective cooling and a decrease in radioactive heat production.

However, Gazel and a team made what they call an astonishing discovery while studying the chemistry of ancient Galapagos-related lava flows, preserved today in Central America: a suite of lavas that shows conditions of melting and crystallization similar to the mysterious Archean komatiites.

Researchers Discover Hottest Lavas That Erupted in Past 2.5 Billion Years (Continued)

Gazel and collaborators studied a set of rocks from the 90 million-year-old Tortugal Suite in Costa Rica and found that they had magnesium concentrations as high as Archean komatiites, as well as textural evidence for extremely hot lava flow temperatures. "Experimental studies tell us that the magnesium concentration of basalts and komatiites is related to the initial temperature of the melt". "The higher the temperature, the higher the magnesium content of a basalt", Gazel said.



X-ray chemical maps of olivines of the Tortugal Suite that record extremely hot crystallization temperatures. Image taken from research paper spearheaded by Esteban Gazel, an assistant professor in the Department of Geosciences, and doctoral student Jarek Trela. Credit: Virginia Tech.

The team also studied the composition olivine, the first mineral that crystallized from these lavas. Olivine a light green mineral that Gazel has obsessively explored in many volcanoes and magmatic regions to search for, is an extremely useful tool to study a number of conditions related to origin of a lava flow because it is the first mineral phase that crystallizes when a mantle melt cools. Olivines also carry inclusions of glass that once was melt and other smaller minerals that are helpful to decipher the secrets of the deep Earth.

"We used the composition of olivine as another thermometer to corroborate how hot these lavas were when they began to cool," Gazel said. "You can determine the temperature that basaltic lava began crystallizing by analyzing the composition of olivine and inclusions of another mineral called spinel. At higher temperatures, olivine will incorporate more aluminum into its structure and spinel will incorporate more chromium. If you know how much of these elements are present in each mineral, then you know the temperature at which they crystallized."

The team found that Tortugal olivines crystallized at [temperature](#) nearing 2,900 degrees Fahrenheit (1,600 degrees Celsius) as high as temperatures recorded by olivines from komatiites making this a new record on lava temperatures in the past 2.5 billion years.

Gazel and collaborators suggest in their study that Earth may still be capable of producing komatiite-like melts. Their results suggest that Tortugal lavas most likely originated from the hot core of the Galapagos mantle plume that started producing melts nearly 90 million years ago and has remained active ever since.

Researchers Discover Hottest Lavas That Erupted in Past 2.5 Billion Years (Continued)

A mantle plume is a deep-earth structure that likely originates at the core-mantle boundary of the planet. When it nears the surface of the planet it begins to melt, forming features known as hotspots such as those found in Hawaii or Galapagos. Geologists can then study these hotspot lava flows and use their geochemical information as a window into the deep Earth.

"What is really fascinating about this study is that we show that the planet is still capable of producing lavas as hot as during Archean time period," Gazel said. "Based on our results from Tortugal lavas, we think that mantle plumes are 'tapping' a deep, hot region of the mantle that hasn't cooled very much since the Archean. We think that this region is probably being sustained by heat from the crystallizing core of the planet."

"This is a really interesting discovery and we are going to keep investigating Tortugal," said Trela, a doctoral student and the first author of the paper. "Although the Tortugal Suite was first discovered and documented more than 20 years ago, it wasn't until now that we have the technology and experimental support to better understand the global implications of this location."

Trela added, "Our new data suggest that this suite of rocks offers tremendous opportunity to answer key questions regarding the accretion of the Earth, its thermal evolution, and the geochemical messages that mantle plumes bring to the surface of the planet."

Read more at: <https://phys.org/news/2017-05-hottest-lavas-erupted-billion-years.html#jCp>

Comets Contributed to Earth's Atmosphere, Says Study of 3 Billion-Year-Old Minerals

Scientists have revealed that some of Earth's atmosphere may have been brought to the planet by comets billions of years ago.

The mystery of how the Earth's atmosphere was formed has long baffled scientists. Some researchers think comets might have originally brought some of the water, organic and atmospheric molecules to Earth that now make up its life.

Now a new study, published in *Nature Communications*, by researchers from The University of Manchester, UK, Centre de Recherches Pétrographiques et Géochimiques (CRPG) and Université de Lorraine (Nancy, France), has found evidence to back up the theory.

These scientists have been analysing tiny samples of ancient air trapped in water bubbles found in the mineral, quartz, which dates back more than three billion years. The team found that the air in the rocks is partly made up of an extremely rare form of the chemical element, xenon. It is known as U-Xe and what makes it so rare is that it isn't usually found on Earth. The component is not present in the Earth's mantle, nor is it found in meteorites.

Therefore, the team believe that the U-Xe must have been added to the Earth after a primordial atmosphere had developed. Simply put, comets are the best candidates for carrying the U-Xe to the planet.

Comets Contributed to Earth's Atmosphere, Says Study of 3 Billion-Year-Old Minerals (Continued)

Co-author, Prof Ray Burgess, from Manchester's School of Earth and Environmental Sciences explains: "The Earth formed too close to the Sun for volatile elements, such as U-Xe, to easily condense and they would have rapidly boiled off the surface and been lost to space.

"The reason that oceans and an atmosphere exist at all is because volatiles were still being added after the Earth formed. The puzzle is in identifying where the volatiles came from and what objects carried them to the early Earth.

"The difficulty is that many of the different volatile ingredients that were originally added have been thoroughly mixed together by geological processes during Earth's long geological history."

To combat this 'mixing' issue the team used tiny samples of ancient air trapped in water bubbles found in quartz in drill cores from the Barberton area of South Africa. The rocks from this region of the continent are extremely old and very well preserved. The team found that, in the Barberton quartz, 3.3 billion year old U-Xe has a composition very different from the xenon found in the Earth's atmosphere today.

Lead author Dr Guillaume Avice from CRPG, said: "We measured the amount and isotopic abundance of xenon in the 3.3 billion year old air with unparalleled precision.



"Xenon is a noble gas which, being chemically inert and having nine isotopes, is an ideal element to reveal the xenon isotopic composition in the Earth's primary atmosphere. This also makes it an ideal way of finding out where the atmosphere came from."

Prof Bernard Marty, who initiated the study and who is also based as CRPG, said: "Our study reveals that 3 billion years ago there was already a xenon component in the Earth's atmosphere different from solar gases and in asteroids. One possibility is that this xenon was from comets."

But the discovery also shows the research possibilities of studying gases found trapped deep in the earth. Dr Avice added: "The study of gases trapped in ancient rocks opens new perspectives in our understanding of the origin and evolution of Earth's volatile elements which are key factors for our planet's habitability."

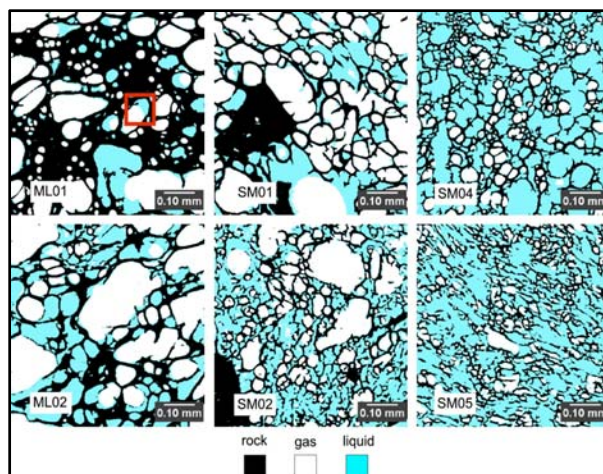
How X-Rays Helped to Solve Mystery of Floating Rocks

It's true some rocks can float on water for years at a time. And now scientists know how they do it, and what causes them to eventually sink.

X-ray studies at the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) have helped scientists to solve this mystery by scanning inside samples of lightweight, glassy, and porous volcanic rocks known as pumice stones. The X-ray experiments were performed at Berkeley Lab's Advanced Light Source, an X-ray source known as a synchrotron.

The surprisingly long-lived buoyancy of these rocks which can form miles-long debris patches on the ocean known as pumice rafts that can travel for thousands of miles can help scientists discover underwater volcano eruptions.

And, beyond that, learning about its flotation can help us understand how it spreads species around the planet; pumice is nutrient rich and readily serves as a seafaring carrier of plant life and other organisms. Floating pumice can also be a hazard for boats, as the ashy mixture of ground-up pumice can clog engines.



The concentrations of liquid and gas in samples of pumice stones are labeled in these images, produced by X-ray microtomography at Berkeley Lab's Advanced Light Source. The images assisted researchers in identifying the mechanisms that enable pumice to float for prolonged periods. Heated pumice (shown in images at the top right and bottom right) samples contain a smaller volume of trapped gas than room-temperature samples. Credit: UC Berkeley, Berkeley Lab

"The question of floating pumice has been in literature for a long time, and it hadn't been resolved," said Kristen E. Fauria, a UC Berkeley graduate student who led the study, published in *Earth and Planetary Science Letters*.

While scientists have known that pumice can float because of pockets of gas in its pores, it was unknown how those gases remain trapped inside the pumice for prolonged periods. If you soak up enough water in a sponge, for example, it will sink.

"It was originally thought that the pumice's porosity is essentially sealed," Fauria said, like a corked bottle floating in the sea. But pumice's pores are actually largely open and connected more like an uncorked bottle. "If you leave the cap off and it still floats ... what's going on?"

How X-Rays Helped to Solve Mystery of Floating Rocks (Continued)

Some pumice stones have even been observed to "bob" in the laboratory sinking during the evening and surfacing during the day.

To understand what's at work in these rocks, the team used wax to coat bits of water-exposed pumice sampled from Medicine Lake Volcano near Mount Shasta in Northern California and Santa María Volcano in Guatemala.

Then used an X-ray imaging technique at the ALS known as microtomography to study concentrations of water and gas in detail measured in microns, or thousandths of a millimeter within preheated and room-temperature pumice samples.

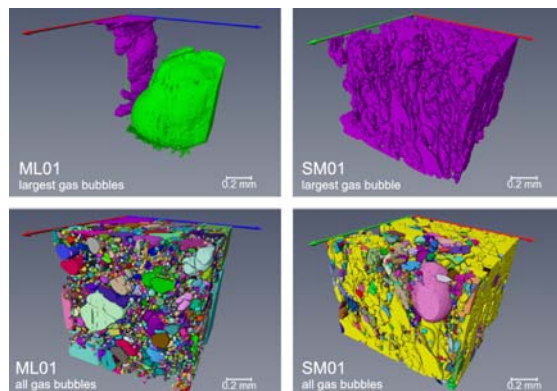
The detailed 3-D images produced by the technique are very data-intensive, which posed a challenge in quickly identifying the concentrations of gas and water present in the pumice samples' pores.

To tackle this problem, Zihan Wei, a visiting undergraduate researcher from Peking University, used a data-analysis software tool that incorporates machine learning to automatically identify the gas and water components in the images.

Researchers found that the gas-trapping processes that are in play in the pumice stones relates to "surface tension," a chemical interaction between the water's surface and the air above it that acts like a thin skin, this allows some creatures, including insects and lizards, to actually walk on water.

"The process that's controlling this floating happens on the scale of human hair," Fauria said. "Many of the pores are really, really small, like thin straws all wound up together. So surface tension really dominates."

The team also found that a mathematical formulation known as percolation theory, which helps to understand how a liquid enters a porous material, provides a good fit for the gas-trapping process in pumice. And gas diffusion which describes how gas molecules seek areas of lower concentration, this explains the eventual loss of these gases that causes the stones to sink.



Individual gas bubbles trapped in two pumice samples (labeled "ML01" and "SM01") are shaded with different colors. The size and connectedness of the bubbles can vary widely within a sample. Credit: UC Berkeley, Berkeley Lab

How X-Rays Helped to Solve Mystery of Floating Rocks (Continued)

Michael Manga, a staff scientist in Berkeley Lab's Energy Geosciences Division and a professor in the Department of Earth and Planetary Science at UC Berkeley who participated in the study, said, "There are two different processes: one that lets pumice float and one that makes it sink," and the X-ray studies helped to quantify these processes for the first time. The study showed that previous estimates for flotation time were in some cases off by several orders of magnitude.

"Kristen had the idea that in hindsight is obvious," Manga said, "that water is filling up only some of the pore space." The water surrounds and traps gases in the pumice, forming bubbles that make the stones buoyant. Surface tension serves to keep these bubbles locked inside for prolonged periods. The bobbing observed in laboratory experiments of pumice flotation is explained by trapped gas expanding during the heat of day, which causes the stones to temporarily float until the temperature drops.

The X-ray work at the ALS, coupled with studies of small pieces of pumice floating in water in Manga's UC Berkeley lab, helped researchers to develop a formula for predicting how long a pumice stone will typically float based on its size. Manga has also used an X-ray technique at the ALS called microdiffraction, which is useful for studying the origins of crystals in volcanic rocks.

Dula Parkinson, a research scientist at Berkeley Lab's ALS who assisted with the team's microtomography experiments, said, "I'm always amazed at how much information Michael Manga and his collaborators are able to extract from the images they collect at ALS, and how they're able to join that information with other pieces to solve really complicated puzzles."

The recent study triggered more questions about floating pumice, Fauria said, such as how pumice, ejected from deep underwater volcanoes, finds its way to the surface. Her research team has also conducted X-ray experiments at the ALS to study samples from so-called "giant" pumice that measured more than a meter long.

That stone was recovered from the sea floor in the area of an active underwater volcano by a 2015 research expedition that Fauria and Manga participated in. The expedition, to a site hundreds of miles north of New Zealand, was co-led by Rebecca Carey, a scientist formerly affiliated with the Lab's ALS.

Underwater volcano eruptions are not as easy to track down as eruptions on land, and floating pumice spotted by a passenger on a commercial aircraft actually helped researchers track down the source of a major underwater eruption that occurred in 2012 and motivated the research expedition. Pumice stones spewed from underwater volcano eruptions vary widely in size but can typically be about the size of an apple, while pumice stones from volcanoes on land tend to be smaller than a golf ball.

"We're trying to understand how this giant pumice rock was made," Manga said. "We don't understand well how submarine eruptions work. This volcano erupted completely different than we hypothesized. Our hope is that we can use this one example to understand the process."

Fauria agreed that there is much to learn from underwater volcano studies, and she noted that X-ray studies at the ALS will play an ongoing role in her team's work.

Continental Patterns of Submarine Groundwater Discharge Reveal Coastal Vulnerabilities

Abstract

Submarine groundwater discharge (SGD) delivers water and dissolved chemicals from continents to oceans, and its spatial distribution affects coastal water quality. Unlike rivers, SGD is broadly distributed and relatively difficult to measure, especially at continental scales. We present spatially resolved estimates of fresh (land-derived) SGD for the contiguous United States based on historical climate records and high-resolution hydrographic data. Climate controls regional patterns in fresh SGD, while coastal drainage geometry imparts strong local variability. Because the recharge zones that contribute fresh SGD are densely populated, the quality and quantity of fresh SGD are both vulnerable to anthropogenic disturbance. Our analysis unveils hot spots for contaminant discharge to marine waters and saltwater intrusion into coastal aquifers.

SGD influences global geochemical cycles and coastal water quality by delivering chemical compounds and dissolved ions from land to sea. SGD includes two primary components: fresh, land-derived groundwater that infiltrates on land, and salty, ocean-derived groundwater that infiltrates offshore and returns to the sea. Although small in volume, fresh SGD exports naturally derived elements such as calcium and silicate at rates that rival those of rivers. Fresh SGD is sensitive to human disturbance, and mixtures of fresh and saline SGD transport nutrients and other contaminants offshore. Therefore, the spatial distribution of fresh SGD has a direct impact on patterns of coastal water quality. High rates of nutrient-rich SGD, for example, contribute to harmful algal blooms and hypoxia. SGD patterns also influence ocean temperature and alkalinity, which are key controls on marine ecological and biogeochemical processes.

To understand the influence of fresh SGD on biogeochemical cycles and coastal water quality, rate assessments are needed at global and local scales. However, fresh SGD is difficult and costly to measure, and observations are scarce. Fresh SGD is heterogeneous and diffuse, unlike river discharge, which is concentrated at discrete and readily measurable points along the coast. Although many techniques exist to measure fresh SGD, most measurements are focused on a handful of well-studied, easily accessible locations. The majority of these locations are on the Atlantic coast of the United States (Fig. 1). In the absence of measurements, water budgets have been used to map fresh SGD at high resolution over small coastal regions and low resolution across the global oceans. These disparate scales of analysis leave critical gaps in our understanding of SGD. High-resolution estimates are needed across large regions to reveal relationships among climate, geology, and SGD and to identify where coastal water resources are vulnerable to degradation.

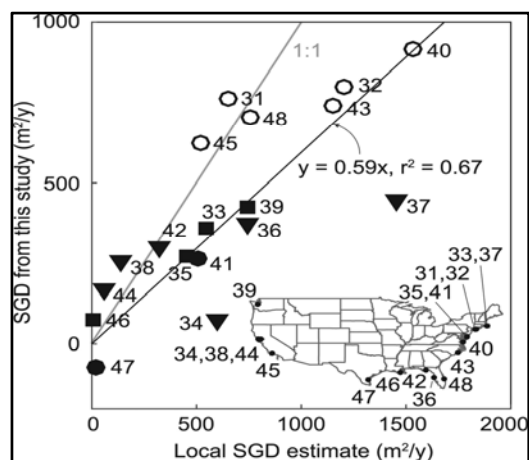


Fig. 1 SGD estimates from this study and the literature. Our SGD values correlate well with local estimates but are generally lower. Circles are from seepage meters, squares are from water budget analysis, and triangles are from multiple methods. Solid symbols indicate fresh SGD estimates. Open circles indicate total (fresh and saline) SGD. We calculated total SGD rates from our fresh rates using the relation $\text{SGD}_{\text{total}} = 1.1 \text{ SGD}_{\text{fresh}} + 470 \text{ m}^2/\text{year}$.

Continental Patterns of Submarine Groundwater Discharge Reveal Coastal Vulnerabilities (Continued)

Here, we present high-resolution continental-scale estimates of fresh SGD across the contiguous United States. Our estimates are based on a simple water budget analysis and state-of-the-art continental-scale hydrography and climate data sets. Recharge zones, or contributing areas, for fresh SGD are defined with high-resolution hydrographic data. We assume that recharge zones are the wedge-shaped land areas outside stream catchments where water flows directly to the coast. We then assume that recharge across these coastal catchments is the component of precipitation that infiltrates and would become base flow to a stream, if a stream were present, but instead flows to the coast. This recharge rate is derived from three decades of reanalysis of climatic data.

To validate our estimates, we compiled 18 local estimates of SGD across the United States. We sought representation from diverse locations along the Pacific, Gulf, and Atlantic coasts and favored studies that used direct near-shore measurements to estimate the fresh component of SGD wherever possible. We excluded sea-based measurements using radon or radium tracer techniques, which can capture a large saline component of SGD. Sea-based measurements sometimes predict substantially larger SGD rates than near-shore measurements, simulations, and water budget-based estimates. Our predicted SGD rates are correlated with local estimates but are consistently lower. The magnitude of discrepancy shows no apparent relationship with geology, climate, land use, or population density. Some field measurements may overestimate fresh SGD, because sites are often selected where fresh SGD is likely to be focused (for example, in permeable sands or bay heads where groundwater flow paths converge). Although field measurements may overestimate fresh SGD, our approach likely underestimates them because coastal recharge zones could import groundwater from upland catchments. These potential additional groundwater sources are not included in our analysis. Furthermore, fresh SGD estimates from water balance approaches tend to decrease with increasing spatial resolution, and our analysis uses high-resolution hydrography data. The approach nevertheless allows for unprecedented mapping of fresh SGD.

At the local scale, our analysis exposes a strong heterogeneity in fresh SGD rates. This heterogeneity can be explained by the variability in land area that contributes groundwater to a given length of coastline. We define the coastal drainage length, which represents the average distance that groundwater travels from its point of recharge to the coast. The drainage length equals the recharge area for fresh SGD divided by the length of coastline where discharge occurs. It varies strongly with local topography and locations of coastal rivers. As a result, the spatial variability in fresh SGD over a typical 100-km segment of shoreline is almost as large as the variability at the continental scale. For example, the coefficient of variation for SGD within 100 km of San Francisco is 0.76, whereas its coefficient of variation along the entire West Coast is 1.10. Because of this strong local variability, SGD measurements at a single site cannot be extrapolated to other nearby sites with high confidence. Moreover, human modifications to coastal drainage networks affect patterns of fresh SGD. For example, fresh SGD rates are low in some areas of Florida with highly altered drainage networks.

At the continental scale, patterns in fresh SGD depend on both drainage geometry and climate. The influence of climate is clear along the West Coast from Southern California to Washington, where net precipitation and fresh SGD both increase by more than 90%, but coastal drainage length is consistent. Meanwhile, the influence of drainage length is evident across East and West coasts. For example, net precipitation is similar in the Pacific Northwest and the mid-Atlantic, but fresh SGD rates are ~50% greater in the Pacific Northwest because of the abundance of long coastal drainage lengths in steep terrain.

Continental Patterns of Submarine Groundwater Discharge Reveal Coastal Vulnerabilities (Continued)

At the continental scale, recharge areas for fresh SGD constitute a small portion of the total land area (0.4% of the contiguous United States). However, these areas drain more water than the continental interior on an areal basis because they receive more net precipitation. The total volumetric rate of fresh SGD from the contiguous United States to the oceans is 15 ± 4 cubic km/year, or $<1\%$ of total land runoff. Because this simple water budget analysis may underestimate fresh SGD by up to 40%, rates may be as high as 25 ± 7 cubic km/year, or $<2\%$ of runoff. These continental-scale estimates are in line with previous estimates for the contiguous United States and the world. Note that saline SGD is substantially greater than the fresh component estimated here and may be as large as 300 to 400% of global runoff, but the fresh component is most vulnerable to contamination and other anthropogenic disturbances. Although volumetrically small, fresh SGD can carry large contaminant mass loads. For example, in some parts of the world, fresh SGD delivers up to 30 times as much nitrogen to the coast as rivers.

The average volumetric flux of fresh SGD per unit length of coastline is $420 \text{ m}^3/\text{year}$, but rates span orders of magnitude. Although SGD is ubiquitous, concentrated discharge zones contribute the majority of fresh SGD to the oceans: Half of all fresh SGD is focused along only 14% of the coast. Interestingly, rates of fresh SGD follow a log-normal distribution, like permeability values for the shallow earth. Permeability is difficult to measure because it ranges by orders of magnitude and is scale-dependent. A particular strength of our analysis is that it does not require permeability data but relies instead on standardized topographic and climatic data sets.

Most of the global population lives near and depends on coastal water resources and fisheries. Thus, high-resolution data sets are imperative for identifying coastal waters that may be vulnerable to “hidden” contaminant loads from fresh SGD. Within the contiguous United States, 3% of the population inhabits recharge areas for fresh SGD, which represent only 0.4% of the total land area. Although 72% of recharge areas were undeveloped as of 2011, conversion to agricultural and urban land use is ongoing. With coastal land development, nutrient loads to groundwater from septic tanks and fertilizers are increasing. Making matters worse, wetland loss reduces coastal resilience to contaminant loading because wetlands are efficient contaminant filters. Regions with above-average fresh SGD and land use development are particularly vulnerable to groundwater-borne contamination, and these regions represent 12% of the coastline. Vulnerable regions include the northern Gulf Coast from Mississippi to the Florida Panhandle, northern Atlantic Coast, and Pacific Northwest. These regions have previously been shown to have high potential nitrogen inputs from SGD to coastal waters. Vulnerable regions should be monitored for direct nutrient inputs from fresh SGD.

High-resolution maps of SGD are also useful for assessing vulnerability of coastal aquifers to saltwater intrusion. In populated areas, groundwater extraction subtracts from the recharge available for fresh SGD and can lead to saltwater intrusion. Most coastal aquifers are more sensitive to groundwater extraction than sea level rise. We predicted vulnerability to saltwater intrusion using an analytical solution for the position of the freshwater-saltwater interface, assuming a population-dependent groundwater extraction rate that directly subtracts from the rate of fresh SGD. Coastlines are considered vulnerable where the toe of the freshwater-saltwater interface reaches the groundwater divide of the coastal aquifer, which implies imminent and full saltwater intrusion. These regions represent 9% of the coastline and include confirmed locations of saltwater intrusion such as Long Island, New York and Los Angeles, California.

Connections Between Groundwater Flow and Transpiration Partitioning

Understanding freshwater fluxes at continental scales will help us better predict hydrologic response and manage our terrestrial water resources. The partitioning of evapotranspiration into bare soil evaporation and plant transpiration remains a key uncertainty in the terrestrial water balance. We used integrated hydrologic simulations that couple vegetation and land-energy processes with surface and subsurface hydrology to study transpiration partitioning at the continental scale. Both latent heat flux and partitioning are connected to water table depth, and including lateral groundwater flow in the model increases transpiration partitioning from 47 ± 13 to $62 \pm 12\%$. This suggests that lateral groundwater flow, which is generally simplified or excluded in Earth system models, may provide a missing link for reconciling observations and global models of terrestrial water fluxes.

Evapotranspiration (*ET*) is the largest terrestrial water flux, typically accounting for more water than runoff and for about 60% of precipitation. It contributes a substantial portion of the global land-energy budget as latent heat (*LH*) flux, which affects regional climate. Evapotranspiration commonly refers to the combination of all evaporation (*E*) from bare soil, water bodies, plant canopy, and sublimation from snow, and transpiration (*T*) through plant stoma during photosynthesis. Here we focus on the partitioning of *ET* into bare soil *E* and plant *T*. Because *T* depends on plant processes, whereas *E* depends on shallow soil moisture and energy availability, these two factors respond differently to physical drivers and stress. Disentangling these fluxes over large scales is a key step toward improved understanding and prediction of watershed dynamics, especially when considering future stresses.

Connectivity between the surface and the subsurface provides a fundamental control on water-energy fluxes and partitioning. Connections between the water table and evapotranspiration have been shown in model simulations and observations of regional systems. Although theory to estimate and simulate evapotranspiration has evolved much over past decades, lateral groundwater flow has yet to be incorporated in continental-scale partitioning estimates. Quantifying the role of groundwater is important, because if partitioning is tied to water table depth and lateral flow, accurate predictions of future water availability will require a more detailed understanding of the underlying processes controlling groundwater surface water interactions than are currently included in most Earth system simulators. Current research on partitioning relies on either isotope approaches or land surface models. These are fundamentally different methods, but both make critical assumptions about groundwater contributions to *T* and simplify groundwater surface water interactions. Discrepancies in partitioning estimates remain, and some have suggested that it may be systematically underestimated by current Earth system models.

We used a continental-scale integrated hydrology model simulation to study the role that lateral groundwater flow plays in evapotranspiration partitioning. We used the ParFlow model, which couple's groundwater and surface water flow with vegetation processes and snow dynamics to solve a complete water and energy balance. The domain covers 6.3 million km² and encompasses major river basins in North America. Simulations were run for one water year at hourly resolution driven by reconstructed meteorology. Transient simulations were initialized using the results of a prior steady-state model over the same domain and additional transient model initialization. The model was compared to 1.2 million transient observations of stream flow, groundwater, and snow, and was shown to match observed behavior.

Connections Between Groundwater Flow and Transpiration Partitioning (Continued)

This simulation generated roughly 1.3 trillion outputs over the 1-year period, covering all key components of the water energy budget. Two variables that exemplify hydrologic stores and land-energy fluxes—water table depth and LH flux (the energy counterpart to ET)—show many scales of detail within these output fields. For example, although groundwater is generally shallower in the more humid eastern region of the domain and deeper in arid western regions, laterally convergent flow drives local variability, creating shallow water tables in river valleys that can supply surface water export. We see similar patterns in LH flux, large-scale trends also driven by climate gradients, yet nested hillslope-scale fluctuations persist.

The integrated model we used provides the ability to explicitly evaluate interactions between variables that are excluded from other global approaches (i.e., water table depth and individual land-energy flux components such as T and E). For example, the ratios of plant transpiration to total evapotranspiration (T/ET) are calculated directly from model outputs and compared to compiled stand-scale and global isotopically based partitioning estimates (Fig. 1, A and B). We see broad agreement between model simulations and estimates across scale; the domain-averaged T/ET of $62 \pm 12\%$ agrees with recent global isotopically derived estimates.

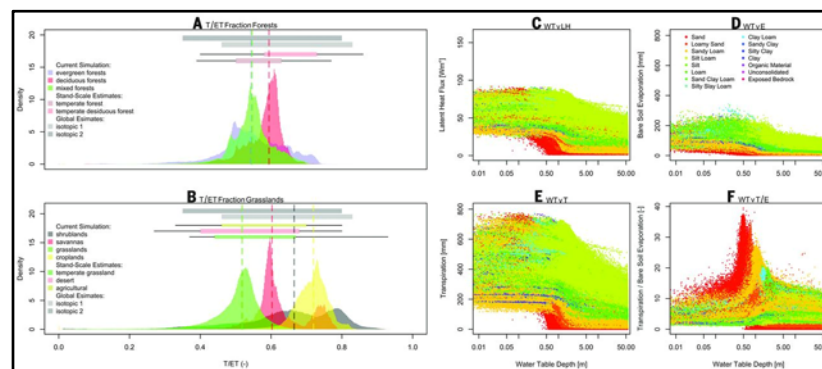


Fig. 1 Simulated annually averaged histograms of evapotranspiration partitioning compare favorably to observations and are related to water table depth. Simulated T/ET ratios (A and B) plotted by land cover type agree with stand-scale estimates and observations and are bracketed by global isotopic estimates, isotopic 1 and isotopic 2, shown here as box plots spanning the $\pm$ mean 1 SD. Scatterplots of water table versus LH flux (C), bare soil evaporation (D), and T (E) suggest that groundwater's role in moderating these fluxes extends across our continental-scale domain. When plotted as a function of water table depth, the T/E ratio (F) peaks at the middle of the groundwater critical depth range, suggesting that T may be as much as 35 times greater than E because of lateral groundwater flow.

To determine the role of lateral groundwater flow in these partitioning estimates, we performed a second simulation that is identical to the base case but allowed only vertical water movement, with no topographic influences or lateral flow. This approach is similar to current practice in land surface models. This “no lateral flow” simulation resulted in a domain-averaged T/ET of $47 \pm 13\%$, suggesting that lateral groundwater flow plays a substantial role in the partitioning of evapotranspiration. This shift was seen systematically across all vegetation types, resulting in a lower prediction of stand and global scale estimates. This indicates that topographically driven lateral flow provides an additional water source for transpiration in groundwater convergence zones.

To evaluate the relationships between partitioning and groundwater directly, we plotted the annual average

Connections Between Groundwater Flow and Transpiration Partitioning (Continued)

LH flux, accumulated *T* and *E*, and *T/E* ratio against water table depth for nine tree and shrub land cover types, colored by soil type: more than 3.2 million points in total (Fig. 1, B to E). The distinct patterns shown in all four plots indicate a connection between water table depth and land-energy fluxes. Plots of *LH*, *T*, and *E* each follow logistic curves with three distinct regions: (i) an energy- or temperature-controlled region at shallow water table depths, where lateral groundwater flow stabilizes soil moisture and removes any water limitation; (ii) a deep disconnected groundwater region where surface fluxes are dependent on precipitation (i.e., water-limited); and (iii) a groundwater-controlled region discussed in prior modeling and observational studies, where land-energy fluxes are correlated with water table depth.

Similar to *T* and *E*, *T/E* ratios (Fig. 1F) also show a clear groundwater dependence; however, they do not follow the same logistic curve behavior as their composite fluxes. Here a maximum *T/E* partitioning [up to 35 in some locations, which also agrees with recent global isotopically derived estimates of *T/E*] occurs at medium groundwater depths (0.5 to 5 m). We showed that this change in *T/E* is due to different depths to available water for the separate *E* and *T* processes. *E* interfaces at the shallow soil surface, whereas *T* draws water deeper from within the root zone. A simple conceptual hillslope model shows that both *T* and *E* follow a similar logistic curve with respect to water table depth, but the depth range over which *E* is sensitive to water table depth is shallower than that for *T*. This shift creates a peak in *T/E* at groundwater depths where *E* is water-limited but *T* is not. This suggests that plants' access to deeper water allows them to draw water after the shallow soil is dry and can shift the balance of *T* partitioning in a manner not currently included in Earth system models.

These results indicate that integrated simulations of the terrestrial hydrologic cycle can provide insights into process interactions that are currently lacking from other approaches, and they further motivate the need to advance model development as well as observations in this area. For example, although the 1-km resolution used for this simulation is fine-scale over such a large extent, there are always processes below the grid scale that might be better represented with increased resolution. Additionally, these simulations do not include any anthropogenic influences, such as groundwater pumping, irrigation, surface water diversions, reservoirs, and urbanization. We envision a road map where these assumptions are systematically relaxed and the model is continuously reevaluated against all available observations.

Although there has been much recent debate regarding *ET* partitioning, our results suggest that lateral groundwater flow processes, currently overlooked in global approaches, may play an important role in characterizing evapotranspiration at large scales. Our integrated hydrologic simulation over most of the major river basins in continental North America suggests that groundwater not only moderates *E* and *T* over the continent, but may also increase the partitioning of *T* substantially. This underscores the importance of including lateral groundwater flow and storage in Earth system models, as well as developing careful multiscale observations of land surface fluxes and water table depth to better explore this relationship. Finally, the impact of groundwater on land-energy fluxes may have important implications for atmospheric simulation and suggests that these feedbacks may go both ways: Changes in water table depth due to widespread worldwide pumping may have a profound influence on land-energy fluxes and climate.

Read more at <http://science.sciencemag.org/content/353/6297/377.full>

Upcomming Rock, Mineral and Fossil Shows

June 2017

11-12 TELLUS SCIENCE MUSEUM, CARTERVILLE, GEORGIA: 100 Tellus Drive, Cartersville, GA 30120. Phone Number (770) 606-5700. Saturday and Sunday 10:00 to 5:00. GEM, MINERAL, FOSSIL, AND JEWELRY DEALERS from across the country will be set up in the Banquet Rooms and outside on the back lawn. You will see rare and exotic jewelry, ancient fossils, and rocks from around the world that you can purchase for your own collection. Many dealers will even honor the Tellus member discount, saving you 10% off your purchase!

August 2017

11-13—DALTON, GEORGIA: Annual show; Dalton Gem and Mineral Jewelry Show, Northwest Georgia Trade and Convention Center; 2211 Dug Gap Battle Rd.; Fri. 2-7, Sat. 10-6, Sun. 11-5; Adults \$4, Children free under 17; Join us for the 26th Annual Dalton Gem and Mineral Jewelry Show! We will have vendors from all across the USA who will have some of the finest gems, minerals, jewelry, beads, pearls and fossils! Custom work and repairs will also be available. We will have door prizes daily as well as a grand door prize! Come check us out!; contact Mohammad Tahir, PO Box 4046, Dalton, GA 30719, (706)-537-8960; e-mail: tahir1269@yahoo.com; Web site: <https://www.facebook.com/pg/daltongemandmineraljewelryshow>

Fernbank Museum Fossil Floors

Watch where you step...you are walking on fossils! The floors of Fernbank Museum are made of 40,000 limestone tiles, each containing fossil remains of animals that lived in a shallow reef more than 150 million years ago.

What kind of rock are you walking on?

These tile floors are limestone that was formed during the Jurassic period, about 150 million years ago. Limestone often contains fossils because it starts out as soft mud. Millions of years ago, this soft mud was on an ocean floor where the remains of dead marine animals, like sponges and snails, sank into it. Over time, layers of this mud accumulated on the ocean floor. The deepest layers were packed down by the weight of mud on top and were cemented together into hard rock, trapping the remains of marine animals in the layers.

What will you find?

Belemnites: These cigar-shaped fossils are some of the easiest to spot. They are ancient relatives of squid.

Sponges: These may be the most difficult to identify in the floor tiles. To the untrained eye, they can look like circles or worm-shaped squiggles.

Ammonites: These distinctive coil-shaped fossils are some of the most beautiful in the floor tiles. They are ancient relatives of the chambered nautilus. A great example is on the stairway across from ***A Walk Through Time in Georgia***, located on Entry Level.

Learn more in the Museum!

Find your way to ***The World of Shells*** at the far end of ***The Star Gallery*** for more information about ammonites and their living relative, the chambered nautilus. Go to the "Life in the Ancient Seas" gallery in ***A Walk Through Time in Georgia*** to find out more about how fossils form and to see examples of ancient sponges.

THE DATE OF THE PG WORKSHOP DOES NOT FALL ON ITS REGULARLY SCHEDULED TIME

May AGS PG Workshop Announcement

Date: **June 3, 2017**
Time: 10:00am to 12:00pm
Venue: Fernbank Science Center Annex
Speaker: Marian Buzon, Ph.D.
Subject: Mineralogy

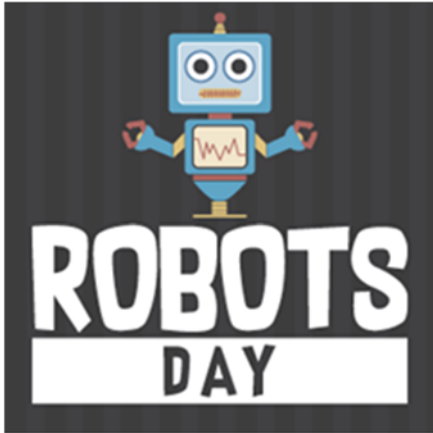
The Fernbank Science Center will not be open the last Saturday of May, therefore we have moved the class to the next Saturday, June 3rd.

Please join us for a Saturday morning of mineralogy. Marian is an assistant professor of geology in the Geosciences Department at the University of West Georgia. She earned her B.S. in geology at the State University of New York in New Paltz and her Ph.D. in geology at the University of Idaho, where she specialized in mineralogy. Her research there involved characterizing commercial talc products and ores: a project motivated by recent talc-asbestos litigation. She currently teaches Physical Geology, and Mineralogy and Crystallography with an optical mineralogy component. She has a continued interest in characterizing and sourcing minerals and enjoys learning about issues between minerals, human health, and litigation.

The classes are open to all, membership in the AGS is not required, but for \$25 per year (\$10 for students) it is quite a bargain. Please consider joining. The AGS is the most active geologic organization in the Southeast. Two hours of professional development credit are available for attendees.

Thanks,
Ken Simonton, P.G.
kws876@gmail.com
Ginny Mauldin-Kinney, P.G.
ginny.mauldin@gmail.com
Atlanta Geological Society
Professional Registration/Career Development Committee

Fernbank Events & Activities



Robots Day

Saturday, June 3, 2017

Get up close with real robots to investigate artificial intelligence and enjoy crafts, activities and demonstrations.

[Learn more](#)



Fernbank Forest Bird Walk

Saturday, June 3, 2017

Join an Atlanta Audubon Society volunteer and discover more about the feathered inhabitants of the forest.

[Learn more](#)



Fernbank Forest Ecosystem

Saturday, June 10, 2017

Enjoy the great outdoors with a Fernbank scientist on a guided tour focusing Fernbank Forest's ecosystem.

[Learn more](#)



Amazon Adventure Day

Saturday, May 27, 2017

Enjoy an Amazonian adventure featuring rainforest-themed crafts, games and hands-on activities.

[Learn more](#)



FERNBANK MUSEUM

of NATURAL HISTORY



WILDWOODS



Wildwoods and Fernbank Forest

WildWoods features 10 acres of lush woodlands, highlighted by hands-on exhibits for all ages, tree pods suspended in the canopy, a nature gallery, immersive adventures, and meandering trails emphasizing dramatic slopes and stunning views. This interpretive nature experience serves as the new entrance into Fernbank Forest.

[Learn more](#)



Mammoths and Mastodons

On view June 17 – August 27, 2017

Explore the world of mammoths and mastodons through fossils, artifacts, engaging interactives, immersive media, and the story of the most complete and best preserved baby mammoth ever found. Explore their habitats, their neighbors, and their human hunters. Investigate current theories about their DNA and extinction, and journey with scientists who continue to study their living cousins—elephants.

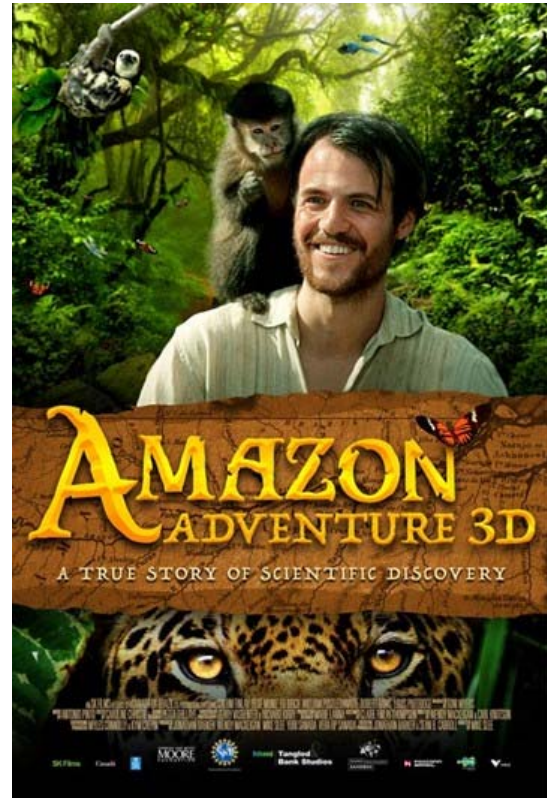
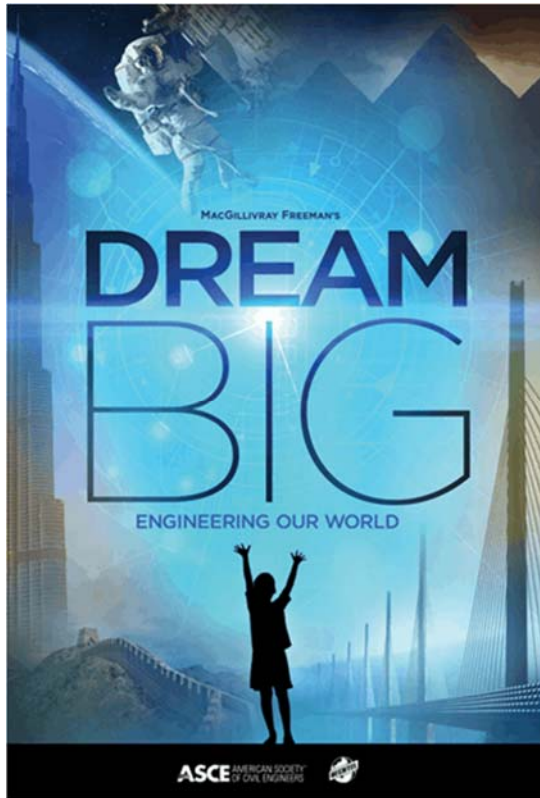
[Learn more](#)



Fernbank Museum of Natural History

(All programs require reservations, including free programs)

Now showing in the Fernbank IMAX movie theater:



[Dream Big](#)

March 4 – June 16, 2017

Take a journey of discovery from the world's tallest building to a bridge higher than the clouds. *Dream Big: Engineering Our World* is a first film of its kind giant screen theatres that will transform how you think about engineering.

[Amazon Adventure](#)

May 20 – September 29, 2017

Experience the epic, true story of explorer Henry Bates' fascinating 11-year journey through the Amazon rainforest as a young man working to unravel a great scientific mystery. See mind-boggling examples of camouflage and mimicry in the visually stunning and biodiverse Amazon and be inspired by Bates' endless curiosity and determination to explore the wilds of nature.

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Past President

Shannon Star George

AGS 2017 Meeting Dates

Listed below are the planned meeting dates for 2017. Please mark your calendar and make plans to attend.

2017 Meeting Schedule

May 30

June 27 Annual Dinner

July No Meeting

August 29

September 26

PG Study Group meetings

Contact Ken Simonton for the details.

June 3 Date Change

June 24

July 29

August 26

September 30

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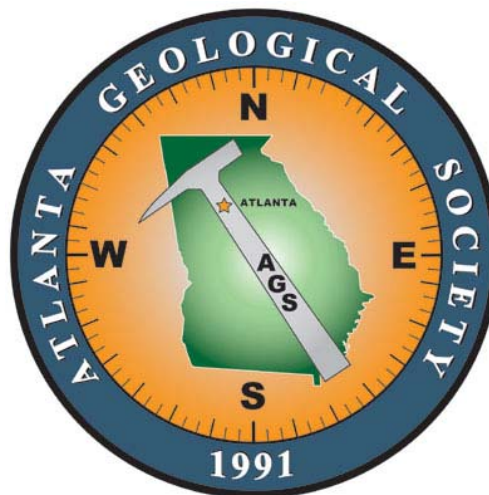
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STUDENT \$10 ☐

PROFESSIONAL MEMBERSHIP \$25 ☐

CORPORATE MEMBERSHIP \$100 ☐

(Includes 4 professional members, please list names and emails below)

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

For further details, contact the AGS Treasurer:

John Salvino johnsalvino@bellsouth.net

Please make checks payable to the "Atlanta Geological Society" and bring them to the next meeting or remit with the completed form to:

Atlanta Geological Society, Attn: John Salvino
3073 Lexington Avenue
Woodstock, Georgia 30189

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