Two-billion-year-old salt rock reveals rise of oxygen in ancient atmosphere

Summary: Salts left over from ancient seawater reveal new information about the oxygenation of Earth’s atmosphere more than two billion years ago.

A two-billion-year-old chunk of sea salt provides new evidence for the transformation of Earth’s atmosphere into an oxygenated environment capable of supporting life as we know it.

The study by an international team of institutions, including Princeton University, found that the rise in oxygen that occurred about 2.3 billion years ago, known as the Great Oxidation Event, was much more substantial than previously indicated.

“Instead of a trickle, it was more like a firehose,” said Clara Blättler, a postdoctoral research fellow in the Department of Geosciences at Princeton and first author on the study, which was published online by the journal Science on Thursday, March 22. “It was a major change in the production of oxygen.”

The evidence for the profound upswing in oxygen comes from crystallized salt rocks extracted from a 1.2-mile-deep hole in the region of Karelia in northwest Russia. These salt crystals were left behind when ancient seawater evaporated, and they give geologists unprecedented clues to the composition of the oceans and atmosphere on Earth more than two billion years ago.

The key indication of the increase in oxygen production came from finding that the mineral deposits contained a surprisingly large amount of a component of seawater known as sulfate, which is created when sulfur reacts with oxygen.

“This is the strongest ever evidence that the ancient seawater from which those minerals precipitated had high sulfate

Sample of two-billion-year-old salt (pink-white recrystallized halite) with embedded clasts of anhydrite-magnesite and mudstone from a geological drill core in Russian Karelia.
Credit: Pavel Medvedev (Karelian Research Centre, Russia).
concentrations reaching at least 30 percent of present-day oceanic sulfate as our estimations indicate,” said Aivo Lepland, a researcher at the Geological Survey of Norway, a geology specialist at Tallinn University of Technology, and senior author on the study. “This is much higher than previously thought and will require considerable rethinking of the magnitude of oxygenation of Earth’s two-billion year old atmosphere-ocean system.”

Oxygen makes up about 20 percent of air and is essential for life as we know it. According to geological evidence, oxygen began to show up in Earth’s atmosphere between 2.4 and 2.3 billion years ago.

Until the new study, however, geologists were uncertain whether this buildup of oxygen — caused by the growth of cyanobacteria capable of photosynthesis, which involves taking in carbon dioxide and giving off oxygen — was a slow event that took millions of years or a more rapid event.

“It has been hard to test these ideas because we didn’t have evidence from that era to tell us about the composition of the atmosphere,” Blättler said.

The recently discovered crystals provide that evidence. The salt crystals collected in Russia are over a billion years older than any previously discovered salt deposits. The deposits contain halite, which is called rock salt and is chemically identical to table salt or sodium chloride, as well as other salts of calcium, magnesium and potassium.

Normally these minerals dissolve easily and would be washed away over time, but in this case they were exceptionally well-preserved deep within the Earth. Geologists from the Geological Survey of Norway in collaboration with the Karelian Research Center in Petrozavodsk, Russia, recovered the salts from a drilling site called the Onega Parametric Hole (OPH) on the western shores of Lake Onega.

The unique qualities of the sample make them very valuable in piecing together the history of what happened after the Great Oxidation Event, according to John Higgins, assistant professor of geosciences at Princeton, who provided interpretation of the geochemical analysis along with other co-authors.

“This is a pretty special class of geologic deposits,” Higgins said. “There has been a lot of debate as to whether the Great Oxidation
Event, which is tied to increase and decrease in various chemical signals, represents a big change in oxygen production, or just a threshold that was crossed. The bottom line is that this paper provides evidence that the oxygenation of the Earth across this time period involved a lot of oxygen production.”

The research will spur the development of new models to explain what happened after the Great Oxidation Event to cause the accumulation of oxygen in the atmosphere, Blättler said.

“There may have been important changes in feedback cycles on land or in the oceans, or a large increase in oxygen production by microbes, but either way it was much more dramatic than we had an understanding of before.”

The authors of the study, in addition to Clara Blättler and John Higgins at Princeton, and Aivo Lepland at the Geological Survey of Norway, include: Mark Claire, Anthony Prave, Aubrey Zerkle and Matthew Warke of the University of St. Andrews in Scotland; Kalle Kirsimäe and Timmu Kreitsmann of the University of Tartu in Estonia; Pavel Medvedev, Alexander Romashkin and Dmitry Rychanchik of the Karelian Research Center in Russia; Kärt Paiste of the UiT Arctic University of Norway; Ian Millar of the British Geological Survey; Justin Hayles of Rice University; Huiming Bao *98 of Louisiana State University; and Alexandra Turchyn of the University of Cambridge.

The study was funded by the Simons Foundation (SCOL 339006 to C.L.B.), the European Research Council (ERC Horizon 2020 grant 678812 to M.C.), the Research Council of Norway (RCN Centres of Excellence project 223259 to K.P. and A.L.), and the Estonian Science Agency (PUT696 to K.K., A.L., K.P., T.K.).

Sample containing two-billion-year-old calcium sulfate minerals (white nodular to bedded anhydrite) from a geological drill core in Russian Karelia. Credit: Kalle Kirsimäe, University of Tartu, Estonia.

2017 and 2018 Ph.D. Recipients and Dissertation Titles

Maria Paula Mateo Fernandez Caso
Environmental Changes and Timing of Events During the Cretaceous-Paleogene Transition: Assessing Consequences of Deccan Volcanism and the Chicxulub Impact
Adviser: Gerta Keller

Xiangtao Xu
Understanding Plant Water Stress and the Terrestrial Carbon Cycle in Tropical Ecosystems: The Roles of Plant Hydraulics, Phenology and Competition
Adviser: David Medvigy

Yajun Peng
Seismological Observations and Numerical Modeling of Slow Earthquakes
Adviser: Allan Rubin

Darcy McRose
Trace Metal Uptake and Use in Soil Diazotrophs and Marine Vibrios: Alternative Nitrogenases, Siderophores, and Quorum Sensing or Efforts of the Very Small to Acquire the Very Scarce
Adviser: François M. M. Morel
Three new faculty members with expertise in geobiology/paleobiology, climate and ocean modeling, and atmospheric modeling and hurricane prediction joined the department in February 2017 and were briefly introduced in last year's Smilodon. Laure Resplandy, Gabriel Vecchi, and Xinning Zhang have now established three new research groups in Guyot Hall, joining Stephan Fueglistaler in our newly reconstituted Climate Cluster. To support their research, the University, the Department of Geosciences, the Princeton Environmental Institute (PEI) and the Princeton Institute for Computational Science and Engineering (PICSciE) jointly invested in new research and computational facilities, which will enhance the experimental capabilities of the biogeochemistry group and the high performance computing capacity of the department as a whole.

Stephan Fueglistaler

The three new faculty members join Stephan Fueglistaler, leader of the climate group, who currently serves as the Director of the program in Atmospheric and Oceanic Sciences (AOS). Fueglistaler joined the department as an Assistant Professor in 2010 and was promoted to Associate Professor in 2015. He previously was a National Environment Research Council (NERC) Advanced Fellow at the University of Cambridge, a Visiting Scientist at the Laboratoire de Météorologie Dynamique, École Normale Supérieure, Paris, a Senior Scientist, ETH Zurich, and a Research Associate, University of Washington. He received his Ph.D. from ETH Zurich and his M.Sc. from the University of Zurich.

The Fueglistaler group studies the interaction of dynamical, physical and chemical processes across the wide range of scales in the atmosphere, and how they shape Earth's climate. Of particular interest are radiatively active atmospheric trace constituents, specifically carbon dioxide, ozone, water vapor and clouds. The abundance of these constituents is governed by source and sink processes, as well as atmospheric transport. In turn, observations of these constituents reveal important information about atmospheric transport processes. Working with observations, theory and numerical models ranging from highly idealized to highly detailed, their work will lead to better understanding of the order of importance of processes for Earth’s climate.

Laure Resplandy

Laure Resplandy has joined the department as an Assistant Professor in the Geosciences department and PEI. Previously, she was a postdoctoral researcher at the Scripps Institution of Oceanography at the University of California-San Diego. Resplandy also completed postdoctoral work at the Laboratoire des Sciences du Climat et de l’Environnement, Paris and at the National Oceanography Center, Southampton. She earned her Ph.D. at the University of Paris-Sorbonne and her M.A. and B.A. at the École Normale Supérieure, Paris.

Resplandy studies biogeochemical cycles and how climate and ocean circulation act upon them. Her research group in Princeton focuses on the interplay between natural variability and long-term changes in carbon sinks and in ocean oxygen content, particularly the fate of ocean areas with very low oxygen levels — the oxygen minimum zones. Resplandy’s research is supported by two new grants from NASA. The first award comes from the NASA EXport Processes in the Ocean from Remote Sensing (EXPORTS) program to quantify the impact of small-scale — from 1 to 100 km — ocean circulation on the marine biological carbon pump. She has also received funding from the PEI Grand
Challenges program to study “The Risk of Permanent Coastal Dead Zones in the Tropical Indian Ocean”.

Resplandy’s second new NASA project is supported by the NASA Orbiting Carbon Observatory (OCO-2) program is to study the “Ocean Processes Controlling Carbon Fluxes during the El Niño Southern Oscillation (ENSO)”. During the record strong 2015/2016 El Niño event, the NASA OCO-2 satellite detected a strong dip in atmospheric CO$_2$, tied to a boost in the Pacific Ocean carbon sink. Resplandy’s team, in collaboration with Kevin Bowman from the Jet Propulsion Laboratory and Ralph Keeling from the Scripps Institution of Oceanography, investigates the processes controlling this boost in the ocean sink, and will quantify the repercussions for the global carbon cycle. This project combines state-of-the-art numerical ocean models run on the brand new PICSciE Tiger super computer with ocean and atmospheric observations, including OCO-2 satellite data and high-precision oxygen measurements from the NASA aircraft ATom campaign and the Scripps stations network. A major goal of this project is to quantify how these natural swings in the ocean carbon sink impact the anthropogenic carbon sink on land and Earth’s climate.

Gabriel Vecchi

Gabriel Vecchi joined the department as a Professor in the Geosciences department and PEI, after having served as a lecturer at Princeton since 2012 and a researcher at the National Oceanic and Atmospheric Administration’s Geophysical Fluid Dynamics Laboratory since 2003. From 2001-03, Vecchi was a research scientist at the University of Washington, where he earlier was a postdoctoral research associate and completed his Ph.D. He earned his B.A. from Rutgers University.

Vecchi’s group is working to understand the mechanisms controlling the behavior of tropical climate and the interactions of the oceans and the atmosphere by combining analysis of observations and global climate models. Vecchi’s recent efforts focus on understanding the interactions between the atmosphere and oceans on timescales from weeks to centuries, including Atmospheric water vapor obtained from a high resolution GFDL global climate model simulation run on Princeton’s Tiger supercomputer, showing hurricanes in the Atlantic and the East Pacific. Princeton’s supercomputing allows scientists to better understand climate, including the mechanisms, sensitivity and impacts of hurricanes. Credit: Courtesy of Gabriel A. Vecchi.

Atmospheric CO$_2$ observed by the OCO-2 satellite in December 2016. (Eldering, A. et al, The Orbiting Carbon Observatory-2 early science investigations of regional carbon dioxide fluxes, Science 358, eaam5745 (2017)).
characterizing the impact of climate change on tropical cyclones and global patterns of rainfall and drought. This work includes understanding how tropical cyclones, such as hurricanes in the Atlantic, have changed over the past century, and how we may expect them to change over the coming decades and centuries, and understanding the mechanisms of the El Niño-Southern Oscillation phenomenon.

Among recent projects is a collaboration with Prof. James Smith, Princeton Civil and Environmental Engineering, and Prof. Gabriele Villarini, Director of the Iowa Institute of Hydrologic Research at the University of Iowa, to understand the impact of tropical cyclones on rainfall and flooding on land. Through the combined analysis of high-resolution global climate models and observations, this work has elucidated the large contribution of tropical cyclones to rainfall and rainfall extremes over land around the globe. In addition to the well-known damaging impact of winds and storm surge from tropical cyclones, tropical cyclones pose a threat through the severe rainfall they can bring to land, as was recently, and tragically, seen in Hurricane Harvey (2017) in Houston. The multiple publications arising from this collaboration indicate that the threat posed by rainfall from tropical cyclones is likely to grow as the planet continues to warm due to increasing greenhouse gases over the coming century.

As hurricanes move northward along the East Coast of the United States, they can sometimes transform into extratropical storms, through a process known as extratropical transition. Extratropical transition places the strongest rainfall to the left of the storm — that is on its landward side — and makes it extend further from the storm center; Hurricane Irene (2011) was a storm that underwent this transition and it resulted in extreme flooding across the eastern United States. With Princeton University Post-doctoral Research Scholar Maofeng Liu (2017) and Hiroyuki Murakami (Princeton Atmospheric and Oceanic Sciences (AOS)/Coopertive Institute for Climate Science (CICS) Research Scholar), Smith and Vecchi have highlighted the particular hazard posed to the eastern United States and Europe by hurricanes that undergo extratropical transition, and have argued that a projected northeastward shift in the preferred tracks of Atlantic hurricanes over the coming century could exacerbate this risk.

To support computational research by the Climate group (which includes Resplandy, Vecchi, and Fueglislater), significant investment was made in new computing resources. Tiger2, is a supercomputer and the largest Linux cluster on campus, and is part of the centralized computational and digital data infrastructure, managed and maintained by PICSciE and OIT’s Research Computing. Tiger2 is a hybrid system with a combination of 392 HPE compute nodes with Intel Skylake chips and 320 NVIDIA Pascal P100 GPUs.

These systems are powerful enough to crunch vast quantities of numbers in a very short time. They can convert an unfathomable amount of information into graphic representations that give researchers virtual images of anything from a strand of DNA to colliding galaxies to climate phenomena, such as future hurricane activity, changes in the global carbon cycle, and processes controlling natural year-to-year fluctuations in Earth temperature.
Our third new faculty member, Xinning Zhang, is a microbiologist with research interests in both biogeochemistry and climate. Zhang is a new Assistant Professor in the Geosciences department and PEI, who joined the faculty after serving as an associate research scholar since 2014 and postdoctoral fellow at Princeton from 2011-14. Zhang also completed a postdoctoral fellowship at the California Institute of Technology. An environmental microbiologist focusing on microbial nutrient and energy transfer in past and present environments, she earned her Ph.D. from the California Institute of Technology and B.S. from Cornell University.

Microbes, ubiquitous but unseen, are vital for the healthy functioning of our planet. As a microbial biogeochemist, Zhang is interested in providing a mechanistic understanding of how microbial metabolism influences biogeochemical cycling and climate in modern and ancient environments. Holistically addressing the role of microbes means that the Zhang group’s research involves experiments carried out both in the field and in carefully controlled laboratory conditions where they apply a wide variety of microbiological and geochemical methods. Current research, carried out in collaboration with a talented and multi-disciplinary, microbe-loving group of students and post-docs, falls under three main foci. The first is biological nitrogen fixation, the main source of nutrient nitrogen on Earth. Members of the Zhang group’s work seek to understand what controls this critical microbial process in past and present ecosystems. Geosciences graduate student Katja Luxem and Postdoctoral Fellow Romain Darnajoux findings show that nitrogen fixation by an understudied group of enzymes can fulfill dual roles in microbial metabolism and can contribute to ecosystem fertility in climate sensitive, high latitude forests.

A second research focus is microbial methane cycling in wetlands, which are the largest source of the potent greenhouse gas methane to the atmosphere. By manipulating peat under different conditions and measuring microbial activities, Zhang and Postdoctoral Research Associate Jared Wilmoth seek to determine whether oxygenated, wetland soils and peats could be overlooked, large sources of methane. Their findings suggest a complex but critical interplay between microbiology, hydrology, and plant carbon chemistry is key to methane production.

A third, and most recently launched research topic, aims to ground-truth the deuterium to hydrogen ratio of lipids, an emerging stable isotope biomarker for microbial metabolism, within marine oxygen minimum zones where microbial metabolic gradients are extremely pronounced. Samples have just come back from a six-week oceanographic research cruise to the Eastern Tropical North Pacific led by GEO department chair Bess Ward and they can’t wait to see what they find out!

For this research, the Zhang mass spectrometry lab was established. In the forefront of the image above is an in-house gas concentrating device coupled to a Thermo DeltaV Plus gas chromatograph — combustion/pyrolysis-isotope ratio mass spectrometer for analysis of carbon, nitrogen, and hydrogen isotopes. In the background is a Thermo ISQ single quad gas chromatograph mass spectrometer for structural identification of volatile compounds. Both instruments are used to advance research on all three research foci.
FROM THE CHAIR

As spring finally arrives in Princeton, it is gratifying to review another busy year in Geosciences. The three new people who joined the Geosciences faculty in February 2017 were briefly introduced in last year’s Smilodon and are featured elsewhere in this issue. The “climate cluster” has made the fourth floor of Guyot into a hive of climate related activity, with every office overflowing with post doctoral and graduate student researchers. One of this year’s Hess Postdoctoral Fellows, Nader Jeevanjee, has joined the group, along with Knox Taylor Emeritus Professor of Geosciences, George Philander, who retired from the department last year. All this activity has sparked the creation of a new weekly seminar series, the GEO/AOS/PEI Climate Seminar, which is held on Monday afternoons. It joins the EGGS (Environmental Geosciences and Geochemistry Seminar) and Brown Bag (Solid Earth Seminar Series) weekly events to cover the breadth of departmental research interests.

Gabriel Vecchi, Professor of Geosciences and the Princeton Environmental Institute (one of the new members of the Climate Cluster) was honored by the American Geophysical Union with the Atmospheric Sciences Section Ascent Award of 2017. The award recognizes research contributions by “exceptional mid-career (academic, government, and private sector) scientists in the fields of atmospheric and climate sciences.” Vecchi was cited “For his creative scientific advances associated with understanding the effects of climate change on the dynamics associated with the Walker circulation, the Hadley circulation, and tropical cyclones”.

Congratulations to John Higgins (whose work in Antarctica in pursuit of the oldest ice on Earth was featured in the Smilodon in 2016), who was awarded tenure and will be promoted to associate professor as of July 2018. In addition to his work on paleatmospheric CO₂ concentrations, deduced from the ice cores, Higgins is widely acknowledged as a leader and pace setter in two main areas: the use of magnesium isotopes to determine the history of seawater based on its major ion composition, and the use of calcium isotopes to understand Earth history despite diagenetic alteration of the rock record.

His work interpreting the diageneric signature in carbonates is potentially paradigm shifting and the world of geochemistry is eager to see how it all shakes out. In the next few years, Higgins will continue to pursue these questions with his recently awarded NSF CAREER grant entitled “What sets the CO₂ thermostat? Insights from the global geochemical cycles of Ca, Mg, and K.”

Higgins uses his Neptune plasma multicolon-lector mass spectrometer for his high through-put high sensitivity isotope analyses, and has established a world class laboratory for these measurements. But apparently, one can never have too many mass spec — GEO must have one of the highest per capita mass spec rates in the world. Thus Higgins is the Co-PI on a newly funded NSF project led by Associate Professor Blair Schoene to acquire a Thermal Ionization Mass Spectrometer for High-Precision Geochronology and Isotope Geology. Schoene was also successful in obtaining a grant to support full time technical staff for his thermochronology laboratory, one of only two such successful applications at NSF this year.

While we are thrilled with the success of these two faculty members in acquiring state of the art instrumentation and putting it to exciting scientific use, providing and maintaining suitably high quality space to accommodate the instrumentation is a real challenge in lovely old Guyot Hall. The cost of renovating the old laboratories to provide clean analytical space can far exceed the cost of the instruments. That is one reason we are eagerly anticipating and heavily involved in the University’s new campus plan. It seems likely that a new building to house GEO, along with EEB (Ecology and Evolutionary Biology) and PEI (Princeton Environmental Institute), is high on the list of priorities. We will be working with the campus planning committees and architects to plan for the next generation of GEO laboratories, research and teaching space.

The biogeochemistry group in the department is approaching the end of an era with the retirement in September of Albert G. Blanke Professor of Geosciences Francois M. M. Morel. Morel is a world leader in the chemistry of natural waters and one of the founders of the field of marine biogeochemistry. His research demonstrated that aquatic chemistry, biochemistry, genetics, and microbiology are critical for understanding the oceans, and in the process, he helped establish the field of marine biogeochemistry. Morel moved to Princeton
after 25 years at MIT and oversaw the development and ascent to world class stature of the department’s biogeochemistry group.

Geosciences undergraduates have led several activities within the department, which you can read about on page 12. Most notably, Princeton Undergraduate Geosciences Society (PUGS) organized and led a departmental field trip to Scotland, from which they will have just returned at the time of publication. Look forward to news and photos from the trip in next year’s Smilodon. I’d like to thank and recognize especially the leadership of Hannah Tandy ‘18 in the success of PUGS, and to acknowledge Hannah, Josh Murray ‘18, William Atkinson ‘18 and SiSi Peng ‘19 for their organizational and leadership work on the Scotland expedition.

The GeoGrad Alumni reunion field trip series continued last year with their most recent trip in June 2017. A write-up of the trip led by Scott Wood to Washington, Idaho, and Montana can be found on page 10.

Three years ago we announced the creation of two new funds intended to support field work by our students. I thank all of those who have contributed; we deeply appreciate your dedication and continued interest in and support of our students. The funds have already made a difference in providing opportunities for our students, and some of their work and experiences supported by these funds are highlighted elsewhere in this issue. For more information about the funds, please contact Nora Zelizer (nzelizer@princeton.edu) or Bess Ward (bbw@princeton.edu).

Danielle Schlessinger with her award at the “Tribute to Teaching” reception hosted by the Graduate School.

**Danielle Schlessinger**, 3rd Year Graduate Student in the Myneni Lab

The graduate school recognized graduate student Danielle’s outstanding teaching abilities by presenting her with one of its annual Teaching Awards. Danielle was an Assistant in Instruction for Professor Myneni’s GEO 363 Environmental Geochemistry: Chemistry for the Natural Systems course in both the Fall 2016 and Fall 2017 semesters.

**Rachel Harris**, 4th Year Graduate Student in the Onstott Lab

At the 17th Annual Student Research Conference hosted by Sigma Xi, Rachel was honored as the top graduate presenter in the category of Microbiology and Molecular Biology.

**Ellen (Xuyuan) Ai**, 3rd Year Graduate Student in the Sigman Lab

**Jack Murphy**, 3rd Year Graduate Student in the Higgins Lab

**Katja Luxem**, 3rd Year Graduate Student in the Zhang Lab

Ellen, Jack, and Katja were three of the ten graduate students from the University selected this spring to join the Princeton Energy and Climate Scholars (PECS).

**Paul Gauthier**, Associate Research Scholar

At the 3rd Annual Princeton Research Day, Paul received the Silver Award for best Poster Presentation in the Graduate, Postdoctoral or Other researcher category.

**Lucia Gualtieri**, Postdoctoral Research Associate

Lucia received the 2017 Keiiti Aki Young Scientist Award at the 2017 American Geophysical Union Fall Meeting.
In June 2017, a group of Geosciences Alumni gathered in Coeur d’Alene to begin a week-long tour through parts of Idaho, Washington and Montana. Under the exceptional direction of Scott Wood *85, the trip combined stimulating geological field work with opportunities for socialization and recreation through some of the most scenic areas in the U.S. The group included alumni, family members and current members of the department of Geosciences who ranged in age from less than one year to senior citizens, with representatives from the graduate classes of 1956 to 2008.

Participants included Steve Bergman *82; Thomas Brocher *78; Richard Chase *63 and Mackie Chase; postdoc Mike Eddy ’11; John Evans *88; Michael Foose *75; Faculty Emeritus Lincoln Hollister, Katherine Hoppe *99; graduate student Jennifer Kasbohm; Chuck Lawson *82; William MacDonald *65 and Nuna MacDonald; Ralph Moberly *56 and Patty Moberley; Eldridge Moores *63 and Judy Moores; Associate Professor Blair Schoene; Karin Sigloch *08, Patrick Regan and baby Dorothee; Rich Vierbuchen *79 and Joanna Ajdukiewicz *77; Scott Wood *85 and Lori Wood; and Mary Yang *88.

The first part of the trip was based at the Coeur d’Alene Resort, providing a scenic and conveniently located home base for the group, as it traveled through the Columbia River flood basalts and the channeled scablands scoured by the Missoula floods. On the first day of field work, the group was joined by University of Idaho faculty members Bill Rember, an expert on fossil beds and Leslie Baker, an expert on environmental geochemistry of mining-contaminated wetlands. The group visited the Cheney-Palouse Scablands tract, and had the opportunity to see coulees, a dry cascade, a gravel pit in a flood gravel bar with foreset bedding, Palouse Falls and sculpted loess hills.

The following day, Dr. Rember brought the participants to his personal excavation of the Clarkia Fossil Beds in his backyard, where everyone was allowed to collect some of these well-preserved Miocene plant, fish and insect fossils. The Miocene fossil beds near Clarkia, Idaho are famous for the exceptional preservation of a wide array of flora and fauna. The fossils are sufficiently well-preserved that organic compounds, including DNA, have been recovered and studied.

To complete the rock cycle, metamorphic rocks were well-represented by kyanite-garnet amphibolites near Orofino, ID; and an acquaintance of Dr. Rember took the group to his private property to dig for Idaho star garnets—and provided a bag of previously dug garnets to all participants!

That evening, the group enjoyed Kasbohm’s presentation of her Ph.D. research on U-Pb geochronology of the flood basalts, in which she drastically refined the chronology of the Columbia River eruptions. The new timeline provides tie-points for the geomagnetic polarity timescale, improves the correlation of its effusion and associated CO₂ release with the mid-Miocene Climate Optimum, and helps constrain geodynamic models for the origins of the flood basalt.

The following day, the group set off for a jet boat ride along the Snake River. The drive from Coeur d’Alene
to Lewiston provided views of the Palouse Hills, some Columbia River basalts (including a paleosol horizon) and the confluence of the Snake and Clearwater Rivers. The jetboat ride provided otherwise inaccessible views of spectacular columnar jointing in the Columbia River basalts. In the evening, the group enjoyed wine tastings at Basalt Cellars in Clarkston, WA and Clearwater Canyon Cellars in Lewiston Orchards, ID. Over dinner, Schoene updated the group on the current status of the department, as well as future plans.

The participants then left Coeur D’Alene and traveled to Montana, through the historic Cataldo Mission and the mining town of Wallace, ID, arriving at the Fairmont Hot Springs Resort in Butte in the evening. The next day, the group was joined by Dr. Chris Gammons of Montana Tech University, an expert on economic geology and environmental geochemistry. Dr. Gammons guided the group through mining and reclamation sites in and around Butte, MT. Butte was once known primarily for its mining industry but now, subsequent to more than 150 years of mining, milling, and smelting, is more “famous” for its environmental issues. The group visited the Berkeley Pit lake, one of the world’s largest accumulations of acid-mine drainage with more than 100 billion liters of water at a pH of 2.5. In addition, there are over 16,000 km of vertical shafts and horizontal drifts and slopes that are flooded with water affected by acid-mine drainage.

That afternoon, the group then embarked on a guided 2.5 mile cave tour in Lewis & Clark Caverns State Park, where they saw stalactites, stalagmites, columns, and helictites in incredible formations. These caverns were formed by dissolution of the basal Mission Canyon Limestone of the Madison Group (Mississippian to early Carboniferous) during late Pliocene-Pleistocene uplift of the London Hills followed by entrenchment of regional rivers. The last full day of the trip, they toured the active Continental Mine in Butte and completed their journey by visiting the Montana Bureau of Mines and Geology, noted for its fine mineral collection.

While the geology of the trip was spectacular, just as wonderful were the new friendships created and the old friendships rejuvenated over the course of the trip. Everyone benefitted from the array of research interests and perspectives represented by the group. Thanks especially to Scott Wood for organizing the trip, as well for serenading the group with his original musical numbers. The group also appreciated the logistical support and insightful presentations by Eddy and Kasbohm who both have ongoing research projects in the region. Join the Geo-Grads for the next Graduate School Alumni Trip—to Italy—in 2019 or 2020 (TBA)! ■
Undergraduate News

In November 2017, Will Atkinson ’18 received the Best Undergraduate Poster Award at the Andlinger Center for Energy and the Environment and Princeton E-ffiliates Partnership Annual Meeting. Will has accepted a two-year High Meadows Fellowship at Climate Central, a Princeton-based organization that combines research and communication on climate change.

The NSF Graduate Research Fellowship Program recognizes and supports outstanding students who are pursuing research-based graduate degrees in science, technology, engineering, and math disciplines. Don Martocello ’18 was awarded an NSF GRFP fellowship and will enter the MIT-Woods Hole Oceanographic Institute (WHOI) Joint Ph.D. Program in Chemical Oceanography. Don will work with Assistant Professor Andrew Babbin *14 to investigate denitrification using microfluids.

This fall, Joshua Murray ’18 will continue his academic career at MIT where he will work with Professor Oli Jagoutz to investigate the influence of plate tectonics on climate.

After graduation, Henry Ogilby ’18 will join the operations team at Flexport, an international logistics company, in their San Francisco office.

Nicole Rinaldi ’18 will begin her graduate studies this August, studying isotopic geochemistry and biogeochemistry under the guidance of Thure Cerling and Diego Fernandez in the Department of Geology and Geophysics in the College of Mines and Earth Sciences at the University of Utah.

Jack Burdick ’19 will spend the summer interning at Colonial Consulting in New York City.

Can hydrous sediments supply water to the deep mantle? Kyle Duffy ’19 will spend the summer trying to answer this question while he works with Associate Professor Takashi Yoshino at Okayama University in Misasa, Japan. Kyle was one of only 12 students from around the world who was selected for the Misasa International Student Internship Program hosted by the Institute for Planetary Materials at Okayama University.

Katie DuRussel ’19 has accepted an internship with the Michigan Department of Environmental Quality, where she will research ground water contamination. In particular, she will be focusing on a group of man-made chemicals known as PFAS (per- and polyfluoroalkyl substances).

Angel Fan ’19 will spend the summer as an intern in the Artificial Intelligent lab at Tencent Technologies in Seattle, WA. Angel will be focusing on machine learning.

This summer, Benjamin Getraer ’19 will be a Biological Field Science Pathways intern for the U.S. Forest Service in the El Dorado National Forest in California.

Princeton Research Day is a celebration of the research and creative endeavors by students and non-faculty researchers at the University. Alec Getraer ’19 won the Gold Award for Undergraduate Poster Presentations at Research Day 2018 for his poster titled “Centimeter Scale River Network Organization.”

Emily Geyman ’19 has been awarded a fellowship through the Princeton Environmental Institute’s Smith-Newton Scholars Program and will spend the month of June doing field work on the Great Bahama Bank for her senior thesis; after returning to Princeton, she will work at NOAA’s Geophysical Fluid Dynamics Laboratory (GFDL).

Jake Martin ’19 will be an environmental consulting intern this summer at AECOM’s office in Hawaii. AECOM is an American multinational engineering firm that provides design, consulting, construction, and management services.

Supported by the Princeton Environmental Institute summer internship program Kimberly Peterson ’19 will be helping to develop an automatic forecasting system and web-based visualization of storm surges and wave modeling associated with tropical cyclones. Kimberly will be working with Assistant Professor Ning Lin in Civil and Environmental Engineering, where they will develop a hazard database so that the large datasets can be viewed effectively on the web and extracted efficiently for various applications.

James Traile ’19 has accepted an internship in the film industry in Hollywood, CA. James will be directing a documentary film and working on television commercials with The Wonderful Company.
Class of 2018 Senior Thesis Titles

Abstracts and full theses can be obtained through the University’s Library at pulsesearch.princeton.edu. Simply search the student’s name and limit the search results by category (Senior Theses).

William A. Atkinson
THE ROLE OF SOIL MINERALS IN TERRESTRIAL CARBON STORAGE: LINKING FIELD AND LABORATORY STUDIES WITH COMPLIMENTARY SPECTROSCOPY METHODS
Adviser: Satish Myneni

Shayne P. McKenna
AN ANALYSIS OF IN SITU X-RAY DIFFRACTION OF SiO2 UNDER SHOCK COMPRESSION
Adviser: Tom Duffy

Keo Z. Chan
NITROGEN ISOTOPIC (δ15N) VARIATION WITH FISH LENGTH IN THE GLOBAL OCEAN: A POTENTIAL INDICATOR FOR GLOBAL ANTHROPOGENIC IMPACT
Adviser: Bess Ward

Joshua Murray
A DETERMINISTIC APPROACH TO GEOCHEMICAL STRATIGRAPHY
Adviser: Blair Schoene

Maricela Coronado
UNDERGROUND HYDROCARBON PIPESINES IN THE UNITED STATES, AND THEIR RELATIONSHIP TO THE CONCENTRATION OF ARSENIC IN GROUNDWATER
Adviser: Frederik Simons

Henry M. Ogilby Jr.
THE ROLE OF ENCAPSULIN NANOCOMPARTMENTS IN ANAEROBIC AMMONIUM OXIDATION
Adviser: Bess Ward

Walker Darling
GROUND-TRUTHING CORAL AS A PROXY: AN EXAMINATION OF THE δ15N OF FOUR CORAL SPECIES ACROSS THE BERMUDA PEDESTAL
Adviser: Danny Sigman

Nicole E. Rinaldi
A GROUND-TRUTHING STUDY OF THE NITROGEN ISOTOPIC COMPOSITION OF ENAMEL BOUND ORGANIC MATTER IN MODERN BISON TEETH
Adviser: Danny Sigman

Donald Edward Martocello III
H-AQUIL: A CHEMICALLY DEFINED CELL CULTURE MEDIUM FOR TRACE METAL STUDIES IN VIBRIO AND OTHER MARINE HETEROTROPHIC BACTERIA
Adviser: François Morel

Hannah Tandy
EVALUATING CARBON AND CLIMATE SENSITIVITIES OF THE NOAA/GFDL EARTH SYSTEM MODEL ESM2Mb TO FORCING PERTURBATIONS DURING THE PALEOCENE-EOCENE THERMAL MAXIMUM
Adviser: Gerta Keller

Erin McCabe
MESOSCALE PROCESSES’ EFFECTS ON SPATIAL AND TEMPORAL VARIABILITY IN THE OCEAN’S BIOLOGICAL CARBON PUMP
Adviser: Laure Resplandy

Congratulations to all of the members of the Class of 2018 for a job well done!
The Department wishes you all the best. Be sure to keep in touch, as we are excited to hear where your careers take you. We hope that you have enjoyed your experience as a Geoscience major and look forward to seeing you at Reunions 2019.
We are pleased to announce the awards presented at
Class Day 2017 and Class Day 2018

Class Day 2017

Arthur F. Buddington Award
Adrian Tasistro-Hart ’17

Edward Sampson, Class of 1914, Prize in Environmental Geosciences
Casey Ivanovich ’17
Paul (Young) Yi ’17

Benjamin F. Howell, Class of 1913, Junior Prize
William A. Atkinson ’18

Chairman’s Award
Kate Begland ’17
Lauren Santi ’17

Sheldon Judson ’40/William E. Bonini ’48 Teaching Award
Adrian Tasistro-Hart ’17

Sigma Xi Book Award
Kellie E. Swadba ’17

Sigma Xi Membership Nominated
Scott Bechler ’17
Kate Begland ’17
Casey Ivanovich ’17
Lauren Santi ’17
Kellie Swadba ’17
Adrian Tasistro-Hart ’17
Anna Van Brummen ’17
Paul Yi ’17

Departmental Honors

Highest Honors:
Casey Ivanovich ’17
Lauren Santi ’17
Adrian Tasistro-Hart ’17
Paul Yi ’17

High Honors:
Kate Begland ’17
Kellie Swadba ’17

Honors:
Scott Bechler ’17
Anna Van Brummen ’17

Class Day 2018

Arthur F. Buddington Award
William Atkinson ’18

Edward Sampson, Class of 1914, Prize in Environmental Geosciences
Donald Martocello ’18
Hannah Tandy ’18

Benjamin F. Howell, Class of 1913, Junior Prize
Emily Geyman ’19

Chairman’s Award
Hannah Tandy ’18

Sheldon Judson ’40/William E. Bonini ’48 Teaching Award
Joshua Murray ’18

Sigma Xi Book Award
Donald Martocello ’18

Sigma Xi Membership Nominated
William Atkinson ’18
Walker Darling ’18
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Hannah Tandy ’18

Departmental Honors

Highest Honors:
William Atkinson ’18

High Honors:
Hannah Tandy ’18

Honors:
Donald Martocello ’18
Joshua Murray ’18
Alumni News

Jonathan Moch ‘12 is a Switzer Environmental Fellow and Ph.D. student in Earth and Planetary Sciences at Harvard University. He earned a 2017 American Geophysical Union (AGU) Outstanding Student Presentation Award for his work on Chinese extreme air pollution events.

Sean Long *11 was recently awarded tenure by Washington State University. He works on tectonic problems in the Himalaya, the Andes, and the western U.S. Cordillera.

Raleigh Martin ’08 is an AAAS Science & Technology Policy Fellow in the Directorate for Geosciences at NSF.

Laura K. O. Smith ’05 and her husband live in Ushuaia, Argentina and have a second vessel for their Antarctic Tour operations with Quixote Expeditions. They include a guest scientist on each trip — contact her if interested (laura.ko.smith@gmail.com).

This fall, a children’s book entitled 50 State Fossils, a Guidebook for Aspiring Paleontologists by Yinan Wang ’05, will be published by Schiffer Books.

Adam Baig *03 has co-founded Meta Innovation Technologies, an interactive educational platform for professionals in the oil and gas sector (www.metatech.ca or via LinkedIn).

Suzan van der Lee *96 is running for president-elect of the Seismology Section of AGU.

Maribeth Price *95 has left the Geology and Geological Engineering Department at South Dakota School of Mines and Technology to become Dean of Graduate Education. Her textbook Mastering ArcGIS Pro is in press, and Switching to ArcGIS Pro will be available in June.

Betsy (Taylor) Schamberger ’93 is Registration Chair for her 25th reunion. Her environmental consulting company does soil and groundwater analysis as part of the due diligence process.

Todd Henderson ’93 has published two books for Cambridge University Press: Outsourcing the Board and The Cambridge Handbook of Classical Liberal Thought. His first novel, Mental State, is coming out in October.

Kabir Roy Chowdhury (Research Associate 1951-1988) is retired from Utrecht University but continues volunteer work for legal refugees, and is considering a possible trip to the Deccan Traps.

In August, Harold Stowell *87 will be running a Geological Society of America (GSA) Thompson Field Forum in British Columbia, along the same Skeena River route he took in 1983 with Lincoln Hollister, Faculty Emeritus during a Geological Association of Canada (GAC)/Mineralogical Association of Canada (MAC) joint field trip. Art Ferri ’86 is Senior Data Scientist for Billtrust in Lawrenceville, NJ.

Jinny Sisson *85 has been elected a Fellow of the Mineralogical Association of America.

After retiring from ExxonMobil, Fred Zelt *85 and Donna are living in Pittsburgh. He sees a lot of neat geology while fundraising for MS on cross-country cycling trips.

Michael Purucker *84 continues as head of NASA’s Planetary Magnetospheres lab. His group’s magnetometers are currently orbiting Jupiter, Mars, and Earth — and later this year, the Sun! Mike will serve as 2019 president of the Geological Society of Washington.

Alumni Note

We had the great pleasure this spring of hearing from a group of alumni from the class of 1960. Led by Ronald Barks, the group included Stephen Jett, Joel Black, Robert Major and William Bryant. Ron, Stephen and Joel contributed to the memoir, Ron doing most of the writing and Steve contributing most of the wonderful photographs. They compiled a memoir of their summer field camp expedition in 1958, to commemorate the 60th anniversary of this memorable, and for some, life changing experience. The group drove the departmental van cross-country to Wyoming (with adventures along the way) and spent two months at Yellow-Bighorn Research Association (YBRA) and nearby sites. In first hand accounts by the several contributors, the reader is regaled with tales of close encounters with a curious hungry bear, a seriously territorial bull, irate local citizens, disturbed rattle snakes, and many examples of generosity and kindness from total strangers, with a good bit of field geology woven in throughout. We made photocopies of the memoir and sent them along with this year’s students on the departmental field trip to Scotland, so that they can all compare notes. After leaving Princeton, the five participants in the 1958 expedition all achieved advanced degrees including three Ph.D.s, a law degree and an MBA. Because time and space are limited for this 2018 edition of the Smilodon, we will save the rest of this story, and details of the group’s alumni updates, for next year’s edition. It’s worth waiting for!
Lydia Fox ‘81 has received the 2018 Distinguished Faculty Award from The University of the Pacific.

Charlotte Allen ’79 runs the “Elements and Isotopes” unit of the Centralized Analytical Research Facility at Queensland University of Technology in Brisbane, Australia. Armed with a dizzying array of instruments (CPMS, SERCON, RAMAN, FTIR, XRD, XRF, SEM, ZHIM), she and her staff analyze whatever comes in the door.

As a United States Geological Survey (USGS) research geophysicist, Paul Okubo ’75 oversees seismic network and data operations at the Hawaiian Volcano Observatory. He is having an incredible time right now monitoring the East Rift Zone eruptions of Kilauea!

At her company, AltaRock Energy, Inc., Susan Petty ’73 is using two 3000m-deep research wells on Newberry Volcano in Oregon to investigate geothermal power. She has started a nonprofit focused on transitioning from coal-fired to geothermal power production. Her husband, Rick Adair, took early retirement from seismology and is now an energy reporter for News Data in Seattle.

Wayne Pennington ’72 is retiring as Dean of Engineering at Michigan Technological University, but will remain active as a Fulbright Scholar at Curtin University in Perth, Australia, researching geomechanical effects of oil and gas production and of underground CO₂ storage.

As USGS Scientist Emeritus, J. David Bukry *67 continues research on nanoplankton as proxies for temperature and upwelling changes in the northeastern Pacific.

In Memoriam
Alfred “Al” Fischer, 1920-2017

Perija Mountains, Venezuela — 1978 — Al Fischer climbing rocky terrain with assistance from local inhabitant while visiting with Will Maze’s *83 and James Kellogg’s *81 in their field areas. Photo courtesy of Virginia Sisson *85 and Will Maze.

Professor of Geosciences, Alfred “Al” Fischer, died peacefully on July 2, 2017; he was 96. Fischer joined the Princeton faculty in the Department of Geological and Geophysical Sciences (now Geosciences) in 1956 and retired in 1984. That same year he joined the Department of Earth Sciences at USC as Emeritus Professor and moved to Los Angeles, partly to please his wife Winnie who had been raised in southern California. Fischer officially retired from USC in 1991.

Al Fischer was born on Dec. 10, 1920, in Rothenburg, Germany, to parents of German extraction who made a fortune in the Old American West and returned to live in Germany. But in 1935 when Hitler came to power they returned to the USA and settled in Watertown, Wisconsin. Fischer received his BSc. and MSc. at the University of Wisconsin in 1939 and 1940, respectively. He worked as a geologist and a professor in the years that followed including at the University of Kansas as an Assistant Professor where he contributed to the successful Treatise in Invertebrate Paleontology co-authored with Moore and Lalicker. Fischer then went on to receive his Ph.D. in 1950 from Columbia University. Between 1951-56 he served as petroleum geologist for Esso in Peru before joining Princeton University.

Al Fischer was a charismatic and forceful personality, full of ideas and capable of inspiring and motivating students and colleagues alike. His former student Tim Herbert *87, (Professor, Brown University) recalled him as a truly great scientist. Patterns in nature fascinated him, and
he made visionary contributions to stratigraphy and paleoclimatology, armed with an amazing intuition and an ability to absorb new developments in earth sciences. In the early 1960s the rapid advances in plate tectonics at Princeton under Professor Harry Hess transformed Al Fischer’s work. “With his characteristic breadth and insights, he began to apply these emerging principles to sedimentary basins and the geology of oceans,” says Herbert.

In the early 1960s, Al Fischer observed that rhythmic patterns in stratification bear the imprint of climate cycles forced by repetitive changes in Earth’s orbit, an idea first proposed in 1895 by legendary G.K. Gilbert (University of Rochester). Rhythmic sedimentation patterns became Al’s life long passion. He demonstrated this idea based on drilling marine sequences in the Cretaceous Western Interior and the Umbria-Marche sequence of Italy. Ultimately, the idea that orbital changes are recorded in rhythmic sedimentation patterns became the accepted explanation for the timing of the great Pleistocene ice ages.

Al Fischer’s most fundamental contribution during the 1970s engaged many of his graduate students. Al realized that Italian pelagic sections offered an amazingly continuous sedimentary rock record that could calibrate biostratigraphic events with the newly emerging discipline of magnetostratigraphy. Together with collaborators Isabella Premoli Silva (foraminifera) and Giovanni Napoleone (paleomagnetics), Al and graduate student Mike Arthur *79, (Emeritus, Pennsylvania State University) provided the first inter-calibration of planktonic biostratigraphy and the paleomagnetic polarity timescale for much of the Cenozoic and Cretaceous (published in landmark papers in the Bulletin of the Geological Society of America).

In Fischer’s 2009 historical overview of this topic he aptly summarized these major achievements as verifying the orbital origins of the major sedimentary rhythms and serving to reduce the age uncertainties of the significant time stratigraphic levels (biostratigraphic and magnetostratigraphic zones) from an order of circa 500 kyr toward the precessional (20 kyr) level (Sedimentology, Vol. 56, Iss. 1, January 2009: 63-94).

But Al was not blind to the pitfalls of this method. In the same publication, he warned future generations of scientists that shallow water platform carbonates are generally riddled with gaps and display variations, which resulted in sedimentary patterns formed by a chain of responses extending through atmospheric and hydroospheric dynamics to geological processes and the dynamics of the biotic systems.... that pose new challenges to the understanding of Earth history.

To many of his former graduate students Al Fischer was always a larger-than-life figure. His laugh was infectious, and he reminded us all to stop and appreciate both humor and the beauty of the natural world, recalls Lisa Rossbacher *83, (President, Humboldt State University). He practiced this advice in his popular course on Modern Carbonate Environments, especially during the end-semester field trip to the Florida Keys. When students admired a sky streaked with linear cloud formations and asked why that was so, Al replied with a smile, “I guess they just have orderly souls.” During snorkeling at John Pennekamp Coral Reef State Park, he showed them corals, sharks, barracuda, seagrass and lots of colorful fish linking this living world with the fossil world observed in rock outcrops.

Al Fischer’s former graduate students also remember him fondly for his irrepressible enthusiasm and curiosity that led him constantly forward. Herbert expressed the sentiments of many: “My greatest memory of Al was him rocking back and forth, eyes closed but smiling, as he pondered some idea, gently mumbling ‘Ja, Ja’ (a relic of his German upbringing, no doubt) as he composed his thoughts. Those of us who were fortunate to work with him found ourselves guided by his vision to amazingly productive areas of earth science inquiry. But most importantly, we learned from Al what a privilege and joy it is to undertake our scientific journeys.”

Lisa Rossbacher fondly remembers: Al opened my eyes — and those of many students and colleagues — to the wonders of the past, as seen through the lens of the present. He brought perspective, culture, experience, connectivity, and humor to the processes of teaching, learning, and exploring. He changed many lives — including mine.

Fischer was the recipient of many honors and awards: the 2009 Mary Clarke Thomson Medal; in 1994 he was elected a member of the United States National Academy of Sciences; the 1993 Penrose Medal, the 1992 Gustav-Steinmann Medal; the 1992 Lyell Medal; in 1991 he was inducted into the Italian Academy of Sciences; the 1982 William H. Twenhofel Medal; the 1972 Leopold von Buch-Plakette Award, German Geological Society.
Kenneth S. Deffeyes *59, Professor of Geosciences, Emeritus, died peacefully on November 29, 2017 at the age of 85. Deffeyes was widely trained as a geological engineer, chemical oceanographer and sedimentary petrologist and joined the Princeton faculty in 1967 when plate tectonics was transforming our understanding of Earth’s mountains and ocean basins. Indeed, plate tectonics had its birth in the Princeton Geology Department, and Deffeyes was pivotal in translating the excitement of this paradigm shift to the undergraduate curriculum. He was a ‘pied piper’ for recruiting students to Geosciences and they came to the department in droves.

Deffeyes was born December 26, 1931 in Oklahoma City to Hazel and J. A. “Dee” Deffeyes, both teachers. Deffeyes’ fascination with Earth sciences began when his father left teaching to become a petroleum engineer, often bringing his young son along to drill sites in Oklahoma and Kansas. The family eventually settled in Casper, Wyoming, where Deffeyes completed high school and developed an interest in collecting minerals at near by Casper Mountain.

In 1953, Deffeyes graduated from the Colorado School of Mines with a degree in geological engineering. He accepted a job from Shell Development Corporation in Houston, but was soon drafted into the U.S. Army, which assigned him to a U.S. Army Corps of Engineers unit that produced topographic maps at the Presidio in San Francisco.

After two years of service, Deffeyes entered Princeton University to study geological engineering, but felt that the largest gap in his education was in sedimentology. Thus, he began his graduate study under sedimentologist Franklin B. Van Houten *41 and that decision turned into a career. For his doctoral thesis, Deffeyes examined volcanic ash beds in Nevada that had been altered to zeolites. He extended that work to sedimentary rocks and his review paper on the subject, along with a memorable 1958 field trip with geologists from Union Carbide Corporation, led to the foundation of the natural zeolite industry.

Upon receiving his Ph.D. from Princeton in 1959, Deffeyes rejoined Shell. While there, Deffeyes researched the origin of ancient dolomite and discovered the first modern marine dolomite. He also became friends with M. King Hubbert, who in 1956 postulated that the amount of petroleum that could be extracted from Earth was finite and that U.S. oil production eventually would peak and decline. Years later, Deffeyes expanded the theory and wrote three books on the subject, *Hubbert’s Peak: The Impending World Oil Shortage* (2001); *Beyond Oil: The View from Hubbert’s Peak* (2005); and *When Oil Peaked* (2010).

Deffeyes left Shell in 1962 to teach at the University of Minnesota and then Oregon State University, where his research focused on lakes and seafloor petrology, and included work that provided evidence of seafloor spreading.

Deffeyes joined the Princeton faculty in 1967
and began teaching GEO 101, the Department’s introductory course. In 1976, Deffeyes teamed up with Department Chair Sheldon Judson ’40 and Prof. Robert Hargraves *59 in writing “Physical Geography,” an influential introductory textbook and the first one to be organized around plate tectonics.

Deffeyes was also a motivating force behind the geology field trips that enlivened geology courses, traveling with Princeton students to sites such as the Isle of Arran in Scotland and Mammoth Lakes, California, where, Deffeyes said, “students can ask questions and find the answers directly from the rock.” The triumph in his teaching was the conversion of his introductory course with short field-based lab exercises to an introductory seminar course with a week-long field trip during the mid-semester fall break. The first such seminar took freshmen to the Mammoth Lakes area in 1988 and allowed them to spend the week exploring active faulting, recent glaciation and young volcanoes. Soon afterwards, Princeton initiated a broad program of freshman seminars that is ongoing, and the Mammoth field trip became the University’s longest-running freshman seminar.

According to Lincoln S. Hollister, Professor Emeritus, “Deffeyes was a ‘utility infielder’ in the department. Wherever someone was needed to fill out an exam committee or thesis defense, Deffeyes could be counted on to bring diversity and wit to the proceedings. He also taught courses over a wide range of subjects. He could ‘play’ any position.”

Deffeyes’ research contributions were equally quixotic. Joseph Kirschvink *79, now a professor at Caltech, recalls Deffeyes taking great interest in Kirschvink’s 1977 discovery of magnetic materials in the abdomens of honeybees, and helped solve a key problem.

“It was difficult back then to locate precisely where the magnetic materials might be,” Kirschvink says. Deffeyes, who was an expert at mineralogy, did a back-of-the-envelope calculation and figured out that the Department’s old Debye-Scherrer X-ray camera could be converted into a stereo (3-D) iron imaging system that could help us determine the iron distribution within the body of a freeze-dried honeybee. As I recall, this involved taping a 3-foot long cardboard tube to the business end of the camera, and putting the bee on a toothpick at the far end, next to the X-ray film. By rotating the bee and taking X-ray snapshots at the Cu-alpha line (that fluoresces with iron), we made stereo image pairs that showed the 3-D distribution of iron. Fun!”

Deffeyes transferred to emeritus status in 1998 but remained curious and engaged. In 2009 Deffeyes wrote a book with his son, Stephen, a graphic designer, titled “Nanoscale: Visualizing an Invisible World” which takes the reader on “a tour through a world too small to see with a microscope.”

Deffeyes’ outsize personality, passion for his work and teaching, and deep knowledge of geological history and petrology are probably best described by John McPhee in his 1981 book “Basin and Range”, in which McPhee follows Deffeyes across the U. S. to observe natural formations that tell the story of Earth’s development. The book became part of McPhee’s Pulitzer prize-winning “Annals of the Former World.” In it, McPhee described Deffeyes as “a big man with a tenured waistline. His hair flies behind him like Ludwig van Beethoven’s. He lectures in sneakers. His voice is syllabic, elocutionary, operatic.”

That voice will be sorely missed.

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**Alumni News cont.**

Jack Lockwood *66 and F. A. Trusdell have recently published a Geologic Map of the Northeast Flank of Mauna Loa Volcano, Island of Hawaii, Hawaii: USGS Scientific Investigations Map 2932-A, the first of five detailed 1:50,000 maps of lava flows at Earth’s largest volcano.

Robert E. Garrison *64, Professor Emeritus, University of California, Santa Cruz, was recently honored with a conference and field trips. Among the attendees were Casey Moore *71 and Ralph Moberly *56.

John H. DeYoung ’64, USGS Scientist Emeritus, has co-authored U.S. Geological Survey Professional Paper 1802: Critical Mineral Resources of the United States —Economic and environmental geology and prospects for future supply, a document which is already influencing national policy.

This summer Patrick Muffler *64 is off to Peru to search for whale fossils (with the Raymond M. Alf Museum of Paleontology) and then to the Galapagos for a Lindblad/National Geographic cruise.
DEATHS

Colin McAneny ’52
March 14, 2017
https://paw.princeton.edu/memorial/colin-c-mcaneny-52

Kenneth Deffeyes, Faculty 1967-1998
November 29, 2017
See departmental memorial in this issue.

Alfred “Al” Fischer, Faculty 1956-1984
July 2, 2017
See departmental memorial in this issue.

Ben Franklin Howell, Jr. ’39
May 12, 2018
https://kochfuneralhome.com/tribute/details/1680/
Benjamin-Howell-Jr/obituary.html

Robert L. Major ’60
April 10, 2017
https://paw.princeton.edu/memorial/robert-l-major-60

Jerome McHugh ’51
April 5, 2016
https://paw.princeton.edu/memorial/
jerome-p-mchugh-51

William G. Melson *64
October 7, 2016
https://paw.princeton.edu/memorial/william-g-melson-64

Frederick J (Sam) Sawkins *63
October 6, 2016
https://paw.princeton.edu/memorial/
frederick-j-sawkins-63

Alan Smith *63
August 3, 2017
http://www.joh.cam.ac.uk/dr-alan-smith-1937-2017

Loren Toohy *53
November 19, 2016
http://vertpaleo.org/Society-News/SVP-Paleo-News/
Obituaries/Loren-Toohy-(1942-2016).aspx

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