CarnegieScience

The Newsletter of the Carnegie Institution

SPRING 2016

EMBRYOLOGY ▫ GEOPHYSICAL LABORATORY ▫ GLOBAL ECOLOGY ▫ THE OBSERVATORIES ▫ PLANT BIOLOGY ▫ TERRESTRIAL MAGNETISM ▫ CASE: CARNEGIE ACADEMY FOR SCIENCE EDUCATION

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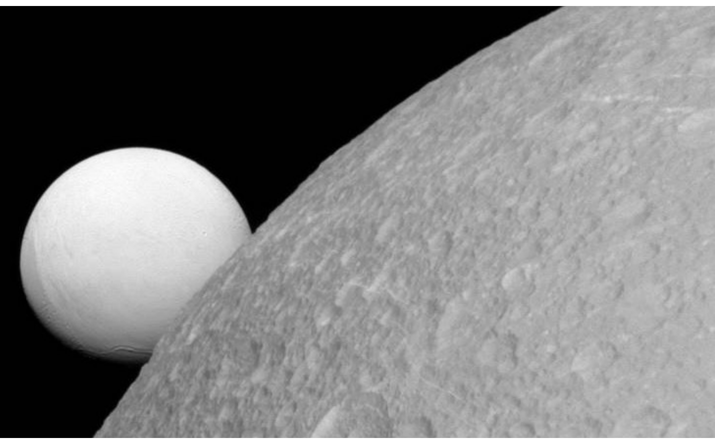

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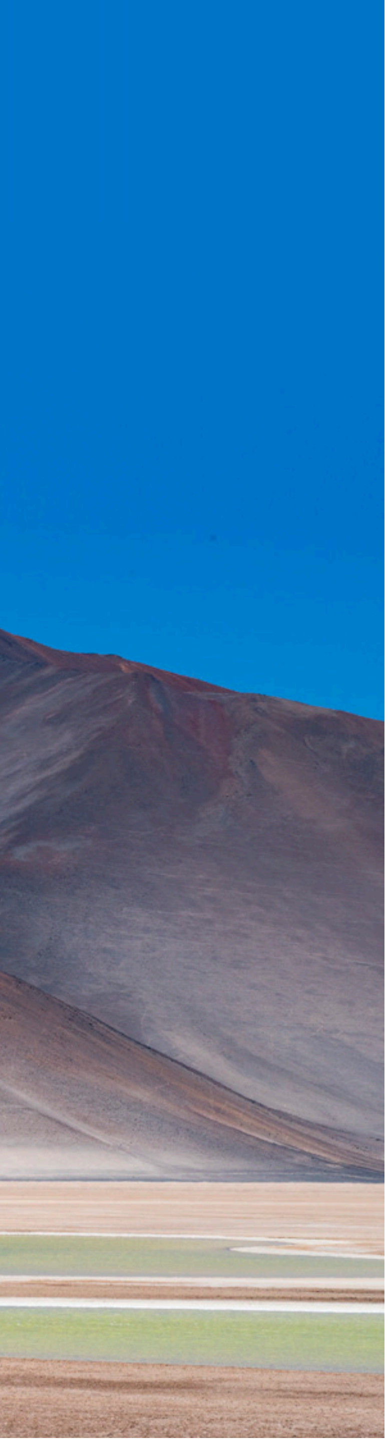
"Understanding the current science of plate tectonics and the surface phenomena it drives will be one of the topics of a 'Handling Hazards' program that Carnegie Science is organizing."

Image courtesy Matt Scott

Judge David Tatel and Dr. Edith Tatel are the convening leaders of Carnegie's new "Handling Hazards" program.

Lara Wagner (left) has been installing seismic instruments in Peru over the last decade. She is with colleague Caroline Eakin.
Image courtesy Lara Wagner



LETTER FROM THE PRESIDENT

Handling Hazards

At about 8pm on September 16, 2015, an enormous earthquake radiated from a fault 25 kilometers (km) deep beneath the Chilean coast. The quake was centered about 50 km out to sea and some 150 km southeast of La Serena, the nearest large town to our telescopes at Las Campanas. Waves reaching about 5 meters came ashore at La Serena, adding waterfront property damage to the damage caused by the quake itself. Fortunately our spectacular telescopes, about 100 km to the northeast, were not affected. The 8.3 Richter scale earthquake, which was followed by a dozen significant aftershocks over two hours, was the latest move by the Pacific plate as it burrows under the west coast of South America. Windows rattled in the capital, Santiago, which is about 240 km from the epicenter. Chile is accustomed to earthquakes and has good systems for responding, so the damage was less than it could have been, but a couple of hundred homes were destroyed and lives were lost. (To learn more read Robin Dienel's story at https://dtm.carnegiescience.edu/news/massive-chilean-earthquake-hits-close-home-carnegie)

Understanding the current science of plate tectonics and the surface phenomena it drives will be one of the topics of a "Handling Hazards" program that Carnegie Science is organizing, with public events this coming June. A team of Carnegie scientists is working with a team of volunteer experts from other organizations to examine current science, policies, and practices in regard to earthquakes, hurricanes, and volcanoes. The convening leaders of this program are Judge David Tatel and Dr. Edith Tatel, long-term friends of Carnegie, and you will be hearing more as the details of the program take shape. In house, we rely on experts such as our seismologist Lara Wagner and our volcanologist Diana Roman, and geologists such as Terrestrial Magnetism department director Dr. Richard Carlson. Dr. Wagner has recently done pioneering work on the fate of the Pacific plate as it sinks under Peru, research that of course has implications for Chile.

Despite the drama and human importance of tectonic plate shifts, the dynamics of Earth's surface are driven by much deeper forces. Many Carnegie scientists are virtually replicating a Jules Verne-style *Journey to the Center of the Earth*, but without ever leaving the surface (so far)! Sometimes the work involves inferences from seismology, other times analysis of diamonds and other minerals that ride explosive kimberlite eruptions to the surface, and other times computer modeling based on fundamental aspects of physics and chemistry. Staff in our Geophysical Laboratory create pressures of millions of times atmospheric pressure to learn about conditions deep inside planets. (We have a striking tour

"Surprisingly, other Solar System planets do not have anything akin to plate tectonics, so understanding why Earth does is an important task."

of the senses among our scientists, with seismologists depending mainly on "hearing," astronomers mainly on seeing, and biologists and geo/cosmochemists depending largely on chemical detection, which could be viewed as olfaction or taste if we didn't use sensitive machines instead.)

The driving forces behind the movements of materials in and on the Earth are immense flows of energy, with fluxes of temperature, material states, gravitational forces, and magnetism. For example, the north and south magnetic poles have reversed polarity about every 200,000-300,000 years. (We are overdue for another reversal, so watch your compass.) More than ever before it is both essential and possible to model such events using a combination of fundamental principles and field measurements. The measurements are in essence a sampling of Earth's history, while modeling based upon principles of physics and chemistry builds our understanding of Earth and allows us to make predictions—subject to uncertainties about the compositions of planet interiors and the peculiar properties of materials under high pressure.

In recognition of the importance of using computation for such studies, the two newest members of the Department of Terrestrial Magnetism, Peter Driscoll and Peter van Keken, are geodynamists who study fluxes of materials and energy in the Earth and in planets far, far away. Surprisingly, other Solar System planets do not have anything akin to plate tectonics, so understanding why Earth does is an important task. Feedback between Earth's interior and surface that occurs via plate tectonics may play a key role in controlling the surface environment and thus contribute to making a planet habitable, or not. Peter and Peter are among the first to take advantage of Carnegie's powerful new computer recently installed in Stanford's new Research Computation Facility. We named the computer "Memex" after a knowledge-accessing machine concept put forth by former Carnegie president Vannevar Bush. Memex supports the growing need in all of our departments for advanced computational science and, who knows, may help us to discover patterns of tectonic movements that help in planning for the most serious earthquake hazards. It is exciting that using field measurements in combination with sophisticated theoretical studies are leading to a whole new series of insights into Earth history and planet formation. Follow our scientific news releases and websites to be part of the action.

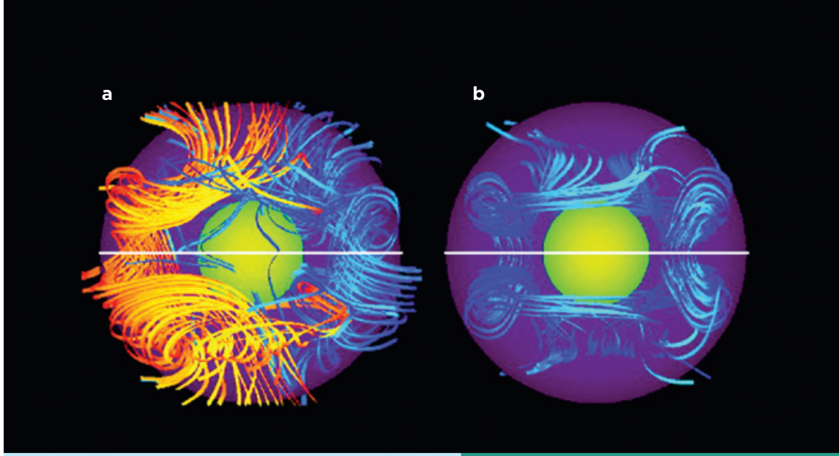
Matthew Scott, *President*

Rick Carlson,

Director of Terrestrial Magnetism conducts fieldwork all over the globe.

In the lab he analyzes thin sections of samples, such as this one from Mongolia mantle xenoliths.

Images courtesy Rick Carlson

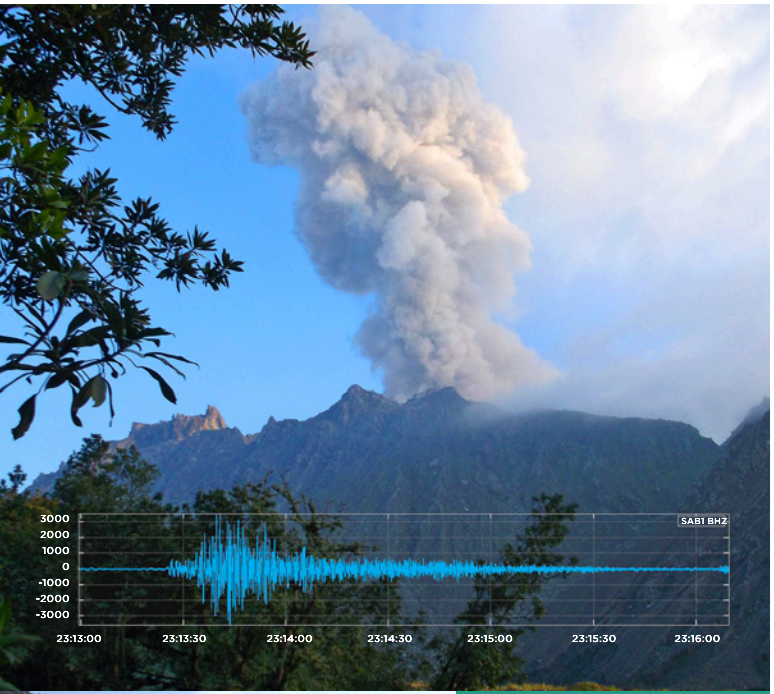


Peter Driscoll

studies Earth's magnetic polarity reversals, which typically occur every 200,000 to 300,000 years.

The model shows magnetic field lines during a reversal (left) and after (right). Color refers to direction of the magnetic field.

Images courtesy Peter Driscoll



Diana Roman

works at the Santiaguito Volcano in Guatemala.

The explosion of Santiaguito (above) is shown in a seismic trace from one of her newly installed instruments.

Images courtesy Diana Roman

Peter van Keken

(left) participates in a discussion during the 2015 GeoPRISMS fieldtrip to Santa Catalina Island, CA, with volcanologists and geochemists Anais Ferot, Pierre Bouilhol, and Christy Till.

Van Keken is a computational geophysicist who works extensively with field- and lab-based scientists to better understand the causes and consequences of plate tectonics.

Image courtesy Julia Morgan

Carnegie Science

embarked on a new high-performance computing facility located at Stanford University. Nearly 100 racks are now operational, among them the Carnegie Memex cluster (shown.)

TRUSTEE NEWS

Board Elects Two New Trustees

The Department of Plant Biology hosted the November board of trustees meetings in California on November 19th and 20th. After board business on Thursday, the department hosted a luncheon and guided demonstrations of their research. There were eleven "living poster sessions." The trustees and other guests broke into groups and toured three sessions each, covering diverse topics including the future of corals, plant pathogens and their hosts, how plants respond to smoke, the dynamics of a carbon-fixing cellular component, innovations in imaging systems, and more.

The Department of Plant Biology hosted the November board of trustees meetings in California.

The board unanimously elected two new trustees: Walter Isaacson, president and chief executive officer of the Aspen Institute, a nonpartisan educational and policy institute based in Washington, D.C., and Katie Lapp, Harvard University's executive vice president.

Walter Isaacson
Image courtesy Walter Isaacson

Walter Isaacson was chairman and chief executive officer of CNN and the editor of *TIME* magazine. He joined *TIME* in 1978 and served as a political correspondent, national editor, and editor of digital media before becoming the magazine's 14th editor in 1996. He became chairman and chief executive officer of CNN in 2001 and then president and chief executive officer of the Aspen Institute in 2003. He has written numerous books including *The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution* (published in 2014), a biographical tale of the people who invented the computer, the Internet, and the other great innovations of the digital age.

Isaacson is a graduate of Harvard College and of Pembroke College of Oxford University, where he was a Rhodes Scholar. He has served on many boards and is active in organizations across a spectrum of disciplines.

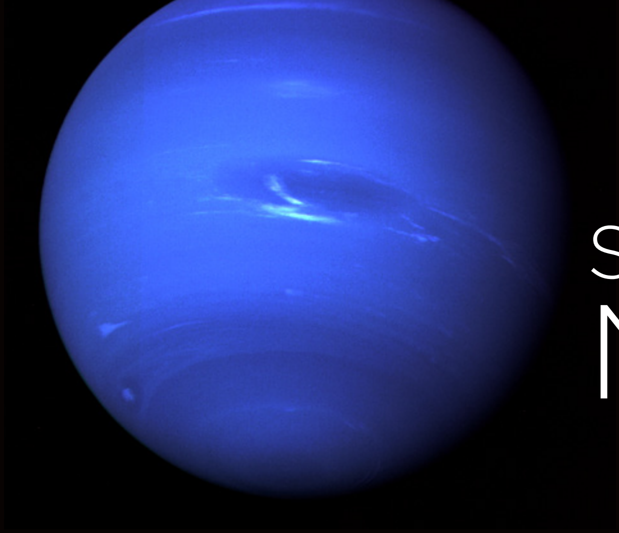
Katie Lapp
Image courtesy Katie Lapp

As Harvard University's executive vice president, Katie Lapp is responsible for the financial, administrative, and operational aspects of the university and is a member of the president's senior management team.

Prior to her appointment at Harvard in 2009, Lapp served as executive vice president for business operations for the University of California. She also served as executive director and chief executive officer for the New York Metropolitan Transportation Authority (MTA) from 2000 through 2006. There she was responsible for the operations, finances, and long-term business strategies of North America's largest regional transportation network.

Prior to joining MTA, Lapp had a distinguished legal career. She was the New York State Director of Criminal Justice and Commissioner of the Criminal Justice Services Department, New York City's Criminal Justice Coordinator, and chief of staff and special counsel to the New York City Deputy Mayor for Public Safety.

Lapp earned a B.A. from Fairfield University and a law degree from Hofstra University. ■



Salty Depths of Neptune and Uranus?

The interiors of several of our Solar System's planets and moons are icy, and ice has been found on distant extrasolar planets. But this ice is not the regular kind of water ice you know. This ice exists under extreme pressures and high temperatures, and it potentially contains salty impurities.

New research from a team including Carnegie's Alexander Goncharov focuses on the physics underlying the formation of the types of ice that are stable under the paradoxical-seeming conditions likely in planetary interiors. Their work, published by *Proceedings of the National Academy of Sciences*, could challenge current ideas about the physical properties found inside icy planetary bodies.

When water (H_2O) freezes, the molecules are bound together in a crystalline lattice held together by hydrogen bonds. Due to the versatility of these hydrogen bonds, ice reveals a striking diversity of at least 16 different crystalline structures. But most of these structures could not exist in the interiors of frozen planets and moons.

Under high pressures, the variety of possible ice structures shrinks, just as the space between its hydrogen-bonded oxygen atoms shrinks as the ice becomes denser. When pressure is increased to more than about 20,000 times Earth's atmosphere (2 gigapascals), the number of possible ice structures is reduced to just two—ice VII and ice VIII. Ordinary ice has a hexagonal structure. Ice VII has a cubic structure. Ice VIII has a tetragonal structure.

As the pressure increases further, both forms of ice transform to another phase called ice X. This happens at pressures around 600,000 times Earth's atmosphere (60 gigapascals), which would be comparable to the pressure conditions found in the interior of an icy-cored planet, such as Neptune or Uranus. Ice X has a whole new kind of symmetrical lattice structure. It's called non-molecular ice, because the water molecule is broken apart and the hydrogen atoms are shared between neighboring oxygen atoms.

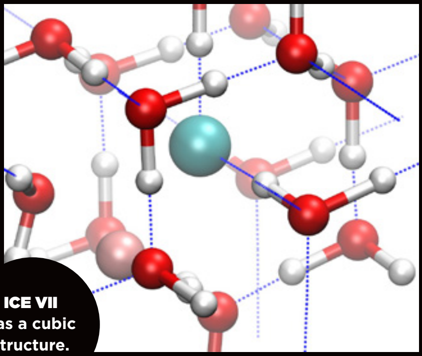
Under similar pressures but higher temperatures, it has been suggested that ice X could possibly transform into a phase of ice that can conduct electricity as hydrogen atoms move freely around the oxygen lattice. But how such ice would be formed at the temperatures found in planetary interiors has remained mysterious.

Because the interiors of icy planetary bodies might also be salty, due to interactions between the ice and the surrounding rocks or a liquid ocean, lead author Livia Eleonora Bove of the Centre National de la Recherche Scientifique (CNRS) and the Université Pierre et Marie Curie in France and the École Polytechnique Fédérale de Lausanne in Switzerland and the rest of the team studied the effects of salts on the formation of the ice X from ice VII.

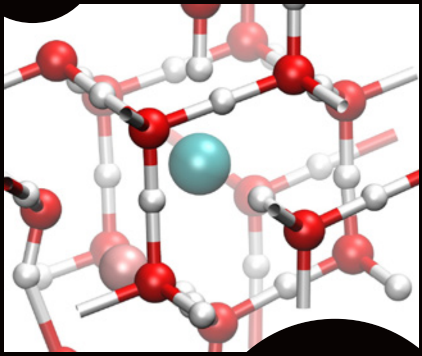
They found that the inclusion of salts in ice VII—both ordinary table salt, sodium chloride (NaCl), and the similarly structured lithium chloride (LiCl)—pushes the formation of ice X to occur at higher and higher pressures. Such salts could easily have been incorporated as impurities when matter accreted during the planetary formation process and became present in rocks or liquid water with which the core ice interacts.

"These findings could challenge our current thinking on the physics occurring in the interiors of icy planetary bodies," Goncharov said. "All of our current assumptions are based on the behavior of ice without any impurities."

The presence of salt could also possibly create the conditions under which the theorized electrically conducting type of ice would form. If so, the team proposed this could explain the magnetic fields of Uranus and Neptune. ■



ICE VII has a cubic structure.



Images courtesy Zamaan Raza

ICE X has a whole new kind of symmetrical lattice structure. It's called non-molecular ice, because the water molecule is broken apart and the hydrogen atoms are shared between neighboring oxygen atoms.

Alex Gonchorov

The other team members are Richard Gaal and Philippe Gillet of the École Polytechnique Fédérale de Lausanne and Zamaan Raza, Adriaan-Alexander Ludl, Stefan Klotz, and Antonino Marco Saitta of the Université Pierre et Marie Curie. (Raza is also of Linköping University in Sweden.)

The Swiss National Science Foundation, the French state funds managed by the Agence Nationale de la Recherche (ANR) within the Blanc International program PACS, and the Investissements d'Avenir program within the framework of the Cluster of Excellence MATISSE led by Sorbonne Universitiés supported this work.

STEM Takes Root at Plant Biology and Global Ecology

Images courtesy Rajnish Khanna

Carnegie researchers on the Stanford campus partnered with the nearby Children's Day School, an independent school from preschool through the eighth grade, to enhance their Science, Technology, Engineering, and Math (STEM) educational activities. The lower school has an extensive organic farm and garden with chickens and sheep, while the middle school has a rooftop succulent and vegetable garden.

In the fall of 2015, a curriculum called Food and Agricultural Sciences was created at the school to integrate STEM education with food and agricultural sciences. The program was adapted from the school's existing "Farm and Garden" curriculum. Rajnish Khanna, a fellow in Plant Biology's Briggs lab and with I-Cultiver, Inc., and Sarah Wally with I-Cultiver, developed the curriculum with two teachers to include ecological and agricultural sciences co-taught by Carnegie scientists. Food science classes included introduction to food labels; the science of taste and flavor; sweeteners and corn; and recipe creation followed by an Iron Chef competition. Khanna organized agricultural science classes, and Wally organized food science classes.

Plant Biology's Heather Cartwright, core imaging director, showed students how to extract DNA from strawberries using household materials. The children asked many questions related to DNA, including its role in environmental adaptation and genetic engineering. Khanna brought plants, cobs, and kernels of *Teosinte*, a corn ancestor, and modern-day maize to the school, provided by Carnegie staff scientist Matt Evans and Davide Sosso of the Frommer lab. The students learned about domestication, genetic modification, genetic engineering, and the role of corn and high-fructose corn syrup in the modern-day food system.

Students from Children's Day School visited the Carnegie campus to experience how scientists conduct plant science and ecology.

In October, eighth-grade students, teachers, and a few parents took a field trip to Carnegie to experience research with Plant Biology and Global Ecology scientists. David Marvin, from Greg Asner's lab, showed images from the Carnegie Airborne Observatory and described how remote sensing is used to predict large-scale ecological responses to climate change in addition to locating illegal and damaging gold mines in the western Amazon lowlands.

Plant Biology's Winslow Briggs discussed how Henry W. Coe State Park recovered from the 2007 Lick Fire. He showed dramatic images of "fire followers"—plants lying dormant for nearly 50 years since the last fire—and opportunistic invasive plants to reveal the role of fire in shaping the forest ecosystem. This work has led to discoveries of the significant role of compounds found in smoke on stimulating germination, and possibly on flowering.

There were two hands-on activities. Plant Biology's Kathy Barton brought mutagenized *Arabidopsis* seedlings to demonstrate the link between genes and phenotypes. The eighth graders used magnifying glasses to identify mutant phenotypes, including seedlings with elongations, albino cotyledons (rudimentary leaves), and those with defects in chlorophyll biosynthesis.

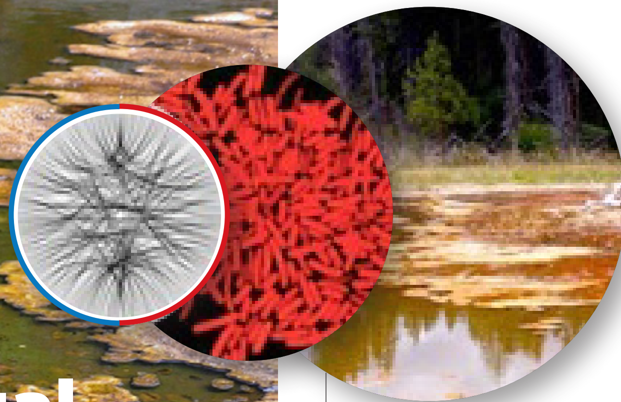
M. C. Yee and José Sebastian from José Dinneny's Plant Biology lab presented GLO-Roots, a proprietary technology developed to image roots in soil. The students took the GLO-Roots rhizotrons—two-dimensional glass pots—apart and discovered the large amount of root mass needed to support the aboveground shoot mass in *Setaria*, a model plant for cereals and biofuels. They also watched videos showing how this technology is applied to study root growth and architecture in response to drought and salt stress.

The program included some embedded math and science questions. In the future, more questions that relate back to classroom work will be added. ■

The students learned about the GLO-Roots technology used to image roots in the soil. They looked at rhizotrons—the two-dimensional glass pots—to see how the roots interact with the soil below.

Plant Biology's Heather Cartwright (far left) showed students how to extract DNA from strawberries using household materials.

Rajnish Khanna, a fellow in Plant Biology's Briggs lab and with I-Cultiver, Inc., talks to students about agricultural science.



This image captures tiers of complexity from genomes to cells to hot spring microbial mat communities of Yellowstone National Park. From left to right: the Circos graph depicts extensive genomic rearrangements between two sequenced cyanobacterial genomes called *Synechococcus* OSA and OS-B' (in red and blue respectively); the middle image shows a population of *Synechococcus* cells cultured in the lab exhibiting natural fluorescence; the third photo is of a microbial mat community in Octopus Spring in Yellowstone National Park.

Images courtesy Michelle Davison and Devaki Bhaya

Quasi-Sexual, Hot Springs Bacteria

To determine genetic diversity and explore evolutionary dynamics, a team including Carnegie's Devaki Bhaya and Michelle Davison examined massive DNA sequencing of bacterial populations that grow in the inhospitable hot springs in Yellowstone National Park. They found an unexpectedly high degree of sharing and exchange of genetic material between the tiny, green, photosynthetic cyanobacteria *Synechococcus*, which are abundant in the scalding environments.

The team discovered that the pattern of differences in genome organization between individuals of the same species indicates that the bacteria transfer DNA, including whole genes, back and forth. This swapping or recombination allows gene variations to spread rapidly through a population. *Science* published their findings.

There is a lot of small-scale genetic diversity in naturally occurring bacterial populations—versus the carefully managed bacterial clones used in laboratory research and clinical work. Bacterial populations in the natural environment represent a dynamic genetic resource that changes over time, but quantifying this diversity, and the exact mechanisms creating its dynamics, has remained elusive.

"Biologists have long been interested in determining the evolutionary and ecological forces that drive the population genetics of bacterial communities," Bhaya explained.

The research team, which also included lead author Michael Rosen and Daniel Fisher of Stanford University, combined the power of so-called deep sequencing with powerful statistical analysis.

They considered several possible scenarios. For instance, one theory predicts that bacterial populations are genetically diverse because they adapt to their surrounding conditions on a very small-scale, local level, leading to distinct subpopulations called ecotypes. Another possibility was that all of the diversity in the bacterial genes is neutral—no particular version of a gene makes an organism more or less fit for its environment. Bacteria reproduce by asexual division, which means that each new generation is stuck with a nearly exact replica of its sole parent's genetic material. Genetic changes can occur through mutation or the transfer of segments of DNA between individual organisms.

The team traced the evolutionary forces that shaped these natural *Synechococcus* populations and found that neither models of neutral drift nor the concept of micro-niches of different ecotypes fit the data. Rather, the population occupies a broad niche that includes a range of environmental conditions. Diversity is created by frequent swapping of genetic material between organisms. This apparently happens often enough that the population can be viewed as quasi-sexual in comparison to organisms like humans, where fertilization combines genes from two parents.

In sexual reproduction, new combinations of genes are the rule. Although this is not generally true for bacterial populations, for these particular hot springs bacteria, new combinations are also the rule, rather than the exception. Since DNA moves between individuals, a new generation will not be stuck with just a copy of its parental genes. Because of this level of variation, natural selection acts on the level of individual genes, not the whole genome. Transfers of DNA happen so often that bacteria can have all sorts of different combinations of genes and gene variants.

"Without deep sequencing and careful analysis, we never would have been able to detect and identify the forces at work, and it will be exciting to discover if these insights extend to other microbial communities," Bhaya noted. "Microbial diversity is found everywhere from deep sea vents to the human gut and in association with plant roots. Using methods such as single-cell sequencing, proteomics, and microscopy will allow exploration of this invisible and important world with great accuracy and depth." ■

(Above) This is a microbial mat community in Octopus Spring of Yellowstone National Park.

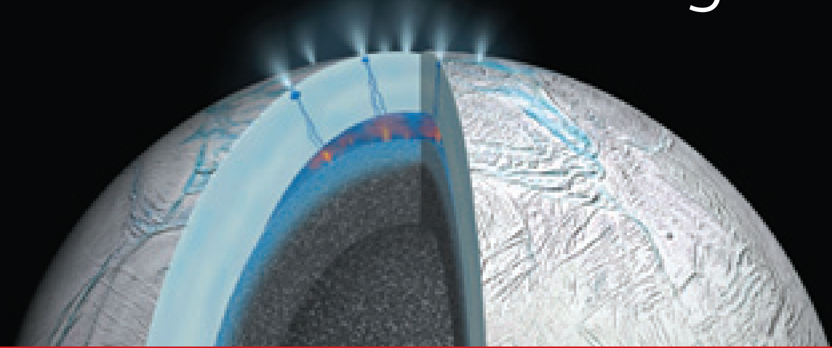
Image courtesy Michelle Davison

(Left) Devaki Bhaya and Michelle Davison work in the lab.

Image courtesy Robin Kempster

The National Science Foundation, the Carnegie Institution for Science, a Stanford Graduate Fellowship, and an IBM fellowship supported this work.

Is Saturn's Moon Linked to Life's Origin?



A team including Carnegie's Christopher Glein, now at the University of Toronto, has revealed the acidity, or pH, of water spewing from a geyser-like plume on Saturn's moon Enceladus. Their findings are an important step toward determining whether life could exist, or could have previously existed, on the sixth planet's sixth-largest moon.

Chris Glein

Enceladus is geologically active and is thought to have a liquid water ocean beneath its icy surface. This hidden ocean is the presumed source of the plume of water vapor and ice that the *Cassini-Huygens* spacecraft has observed venting from the moon's south polar region. When there's the possibility of liquid water, scientists ask whether life could be supported.

The team, including lead author Glein, John Baross of the University of Washington, and J. Hunter Waite, Jr., of the Southwest Research Institute, developed a new chemical model based on mass spectrometry data of ice grains and gases in Enceladus' plume to determine the pH of Enceladus' ocean. The pH indicates how acidic or basic the water is. It is fundamental for understanding geochemical processes occurring inside the moon. The journal *Geochimica et Cosmochimica Acta* published their work.

The team's model used observational data from two Cassini teams, including one led by coauthor Waite. It showed that the plume, and by inference the ocean, is salty with an alkaline pH of about 11 or 12, which is similar to that of glass-cleaning solutions of ammonia. It contains the same sodium chloride (NaCl) salt as our oceans here on Earth. Its additional substantial sodium carbonate (Na_2CO_3) levels make the ocean more similar to our planet's soda lakes such as Mono Lake in California or Lake Magadi in Kenya. The scientists refer to it as a "soda ocean."

"Knowledge of the pH improves our understanding of geochemical processes in Enceladus' 'soda ocean,'" Glein explained.

The model suggests that the ocean's high pH is caused by underwater geochemical changes called serpentinization. On Earth, serpentinization occurs when certain kinds of so-called ultrabasic or ultramafic rocks, which are low in silica and high in magnesium and iron, are brought up from the upper mantle to the ocean floor and chemically interact with the surrounding water molecules. Through this process, these rocks are converted into new minerals, including serpentine, and the fluid becomes alkaline. On Enceladus, serpentinization would occur when ocean water circulates through a rocky core at the bottom of its ocean.

"Why is serpentinization of such great interest? Because the reaction between the metallic rocks and the ocean water also produces molecular hydrogen (H_2), which provides a source of chemical energy that is essential for supporting a deep biosphere in the absence of sunlight inside moons and planets," Glein said. "This process is central to the emerging science of astrobiology, because molecular hydrogen can both drive the formation of organic compounds like amino acids that may lead to the origin of life and serve as food for microbial life such as methane-producing organisms. As such, serpentinization provides a link between geological processes and biological processes. The discovery of serpentinization makes Enceladus an even more promising candidate for a separate genesis of life."

Beyond the search for life-hosting conditions on other planetary bodies, the team's work demonstrates that it is possible to determine the pH of an extraterrestrial ocean based on chemical data from a spacecraft flying through a plume. This may be a useful approach to searching for habitable conditions in other icy worlds, such as Jupiter's moon Europa.

"Our results show that this kind of synergy between observations and modeling can tell us a great deal about the geochemical processes occurring on a faraway celestial object, thus opening the door to an exciting new era of chemical oceanography in the Solar System and beyond." Glein added. ■

The *Cassini-Huygens* spacecraft captured photos of two of Saturn's moons, Enceladus (far) and Dione (near).

This close flyby by NASA's *Cassini-Huygens* spacecraft shows Saturn's active moon Enceladus.
Image courtesy NASA/JPL-Caltech/Space Science Institute

(Above Left) This diagram illustrates the possible interior of Saturn's moon Enceladus, including the ocean and plumes in the south polar region, based on *Cassini-Huygens* spacecraft observations.
Image courtesy NASA/JPL-Caltech

The Deep Carbon Observatory, the Carnegie Institution for Science, the NASA Astrobiology Institute, and the Cassini mission supported this work.

AWARDS & RECOGNITION

Greg Asner

ELECTED FELLOW OF THE AMERICAN GEOPHYSICAL UNION

Carnegie investigator Greg Asner was elected a Fellow of the American Geophysical Union (AGU) last July. He was one of 60 new members. The honor is given "to individual AGU members who have made exceptional scientific contributions and attained acknowledged eminence in the fields of Earth and space sciences." Asner was hired as the Department of Global Ecology's first staff addition in 2001. He has pioneered new methods for investigating tropical deforestation, degradation, ecosystem diversity, invasive species, carbon emissions, climate change, and much more using satellite and airborne instrumentation, coupled with on-ground fieldwork. His innovative techniques measure the chemistry, structure, biomass, and biodiversity of the Earth in unprecedented detail over massive areas not thought possible before.

Winslow Briggs

AWARDED HONORARY DEGREE FROM HEBREW UNIVERSITY

Winslow Briggs, director emeritus and staff scientist at Plant Biology, was awarded the degree of Doctor Philosophiae Honoris Causa of the Hebrew University of Jerusalem for his "scientific leadership and groundbreaking contribution in the field of photobiology." The award letter stated that "Your outstanding scientific achievements in photo biological studies on light-driven leaf movements, namely the physiology, biochemical and molecular interactions of light with plants and the control of plant development processes by plant photoreceptors gained worldwide recognition." Briggs is an international leader in molecular biology research for how plants respond to light for growth and development and for understanding blue-light photoreceptor systems. He was director of Carnegie's Department of Plant Biology from 1973 to 1993 and still runs his lab.

Image courtesy Robin Kempster

Chris Field

THE RECIPIENT OF THE SCHNEIDER AWARD

Chris Field, the founding director of Carnegie's Department of Global Ecology, is the recipient of the fifth annual Stephen H. Schneider Award for Outstanding Climate Science Communication by Climate One. Field has been a pioneer in developing new approaches to understand the large-scale function of Earth's ecological systems for more than 20 years, making major contributions to physiological ecology, ecosystem ecology, biogeochemistry, and climate science. The $15,000 Schneider Award is given to a natural or social scientist who has made extraordinary scientific contributions and communicated that knowledge to a broad public in a clear and compelling fashion.

Image courtesy Liz Mangelsdorf

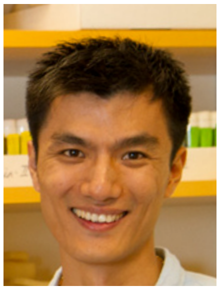
Wolf Frommer

ELECTED TO THE GERMAN ACADEMY OF SCIENCES

Wolf B. Frommer, at Carnegie's Department of Plant Biology, was elected a member of the German Academy of Sciences—Leopoldina, one of the world's oldest national academies in July. Leopoldina has a membership of about 1,500 outstanding scientists from Germany, Austria, Switzerland, and other nations. The organization is "dedicated to the advancement of science for the benefit of humankind and to the goal of shaping a better future." Frommer has had a distinguished career in plant sciences in both Germany and the United States. His work provides the foundation for increasing the yield of crops and bolstering the world's food supply, and even for understanding the processes of some human diseases, such as diabetes and cancer.

Image courtesy Robin Kempster

Martin Jonikas



Zhao Zhang

Martin Jonikas & Zhao Zhang

RECEIVED PRESTIGIOUS NIH AWARDS

In October two researchers, Martin Jonikas of Carnegie's Department of Plant Biology and Zhao Zhang of the Department of Embryology, were awarded the New Innovator and Early Independence Awards, respectively, from the National Institutes of Health (NIH). Traditionally, NIH has supported research projects, not individuals. However, "to identify scientists with ideas that have the potential for high impact, but that may be too novel, span too diverse a range of disciplines, or be at a stage too early to fare well in the traditional peer review process" they created several awards in the High-Risk, High-Reward Research Program to recognize individuals to accelerate the scientific progress. The NIH Director's Pioneer, New Innovator, and Transformative Research Awards encourage "outside-the-box thinkers" to pursue innovative ideas . . . " Martin Jonikas is the 2015 recipient of the New Innovator Award. Zhao Zhang received the NIH Director's Early Independence Award (EIA).

Steve Shectman

RECEIVED MUHLMANN AWARD

In October astronomer and instrumentation expert Stephen Shectman of the Carnegie Observatories was awarded the Maria & Eric Muhlmann Award of the Astronomical Society of the Pacific "for important research results based upon development of groundbreaking instruments and techniques." Shectman investigates the large-scale structure of the distribution of galaxies. He searches for ancient stars, develops novel and creative astronomical instruments, and constructs large telescopes. He was the project scientist for the 6.5-meter Magellan telescopes and is largely responsible for their superb quality.

Zhiyong Wang

RECEIVED HUMBOLDT AWARD

Plant Biology's Zhiyong Wang is the recipient of the Humboldt Research Award, one of Germany's most-prestigious prizes. Granted by the Alexander von Humboldt Foundation up to 100 times each year, the award honors academics "whose fundamental discoveries, new theories, or insights have had a significant impact on their own discipline and who are expected to continue producing cutting-edge achievements in the future." Recipients must be nominated by an established German academic or by a previous winner working abroad in conjunction with a colleague in Germany. The award enables winners to spend up to one year collaborating on a long-term research project with colleagues at a German institution.

Image courtesy Robin Kempster

★ AWARDS ★ & RECOGNITION

Matt Sieber
HONORED WITH FIRST CARNEGIE "POSTDOCTORAL INNOVATION AND EXCELLENCE" AWARD

Matt Sieber (left) is with Allan Spradling at the PIE celebration.
Image courtesy Christine Pratt

Matthew Sieber, a postdoctoral fellow at the Department of Embryology, has been honored for his extraordinary accomplishments, through a new program that recognizes exceptional Carnegie postdoctoral scholars who have demonstrated both scientific accomplishments and creative endeavors beyond what is expected.

Nominations for the Postdoctoral Innovation and Excellence (PIE) Awards are made through the department directors, and the award recipient is chosen by the Office of the President.

Under the program, one postdoc is honored every quarter for their extraordinary accomplishments. The award recipient is given a prize of $1000 and is the guest of honor at a departmental gathering where all postdocs can enjoy some celebratory pies.

Sieber is recognized as "a creative researcher, interactive colleague, and selfless mentor" in the Department of Embryology. Through his research, he has made substantial connections between metabolism and reproduction, an area that previously lacked serious progress.

Sieber's results have exciting implications for both basic research and medicine.

He exemplified the Carnegie style of science by taking an unconventional path. His work shows that mitochondria, an energy-producing cellular organelle, are far more dynamic and responsive to external signals than expected. The finding likely applies to a broad spectrum of animals.

Seiber, Allan Spradling, and Michael Thomsen, also of Carnegie, have a paper in *Cell* that uses the fruit fly to dissect the links between metabolism and egg development. The team believes their findings are directly applicable to understanding polycystic ovary syndrome-caused human infertility.

Sieber also demonstrates a strong engagement with his department. His high level of interaction with colleagues is further evidenced by the growing number of people from diverse labs who cite him in their acknowledgments.

Carnegie president Matt Scott remarked, "I've enjoyed getting to know Matt during my visits to our Embryology Department. Embryology has a distinguished history of mentorship, with many of its graduating scientists having had profound effects on science, education, and policy around the world. Matt is exactly the kind of scientist Andrew Carnegie had in mind to support. I am confident that Matt's creativity and spirit will lead to continued success in science and expect he will be a fine mentor for his future advisees." ■

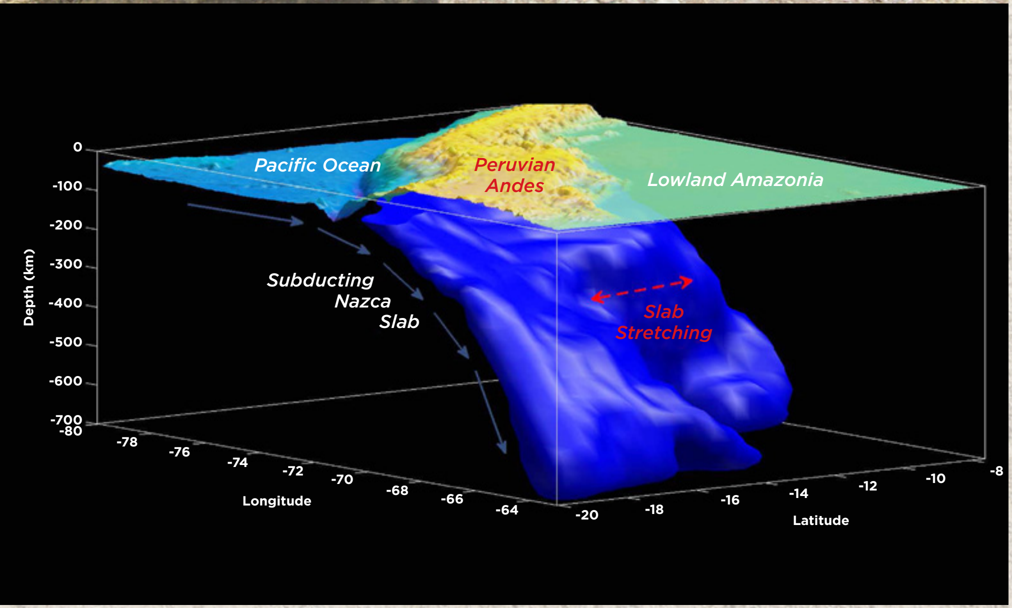
New observations from an international geophysics team, including Carnegie's Lara Wagner, suggest that the standard belief that the Earth's rigid tectonic plates stay strong when they slide under another plate and sink into the deep Earth may not be universally true. The new work suggests that the Nazca slab in Peru may be relatively weak and deforms easily. The research was published in the November 23rd issue of *Nature Geoscience*.

Typically during subduction, plates slide down into the mantle at a fairly steep angle, sinking at a constant rate into the warmer, less-dense mantle material. However, in a process called flat-slab subduction the lower plate moves nearly horizontally underneath the upper plate, sometimes for great distances. A consequence of flat-slab subduction is that the volcanism and mountain formation that normally occurs within a couple of hundred kilometers of the plate boundary moves far inland. The largest flat slab is found beneath Peru, where the oceanic Nazca Plate is being subducted under the continental South American Plate.

Scientists image structures in the deep Earth by observing how seismic waves travel through it. Their speed can reveal structural, compositional, and dynamic features of what lies below. In particular, the crystals in the plate can form an organized fabric that results in seismic waves traveling at different speeds in different directions, a phenomenon known as seismic anisotropy.

Oceanic plates form at mid-ocean ridges where plates are pulled apart and volcanism fills in the gap to create new crust that gradually moves away from the ridge. The movement of the plate causes the most abundant mineral in Earth's interior, olivine, to align with the direction of plate growth. This olivine structure is then "frozen" into the oceanic plate and stays with the plate as it travels across the Earth's surface. The aligned olivine causes seismic waves to travel at different speeds in different directions, depending on whether or not they are going "with the grain" or "against the grain." In typical steep-angle subducting slabs, observing these subtle differences in seismic wave speeds within the down-going plate is very difficult. However, with the unique flat-slab geometry of the Nazca slab, seismic waves that travel through the deep part of the slab (below 125 miles, or 200 kilometers) are unusually accessible using land-based seismometers.

SURPRISE: Stretchy Slabs in Deep Earth



The scientists measured seismic waves at 15 local seismic stations over two and a half years from 2010 to 2013 and at seven distant stations located on different continents. They found that the distant and local data readings both suggested that the frozen olivine structure within the slab had vanished and been replaced by a new unexpected structure in an opposing orientation. The best explanation is that the slab's interior was stretched or deformed during subduction. This means that slabs are weak enough to deform internally in the upper mantle over time. The researchers believe that the deformation associated with stretching of the slab as it bends to takes on its flat-slab shape was enough to erase the frozen olivine structure and create a new alignment that closely follows the contours of the slab bends.

"Imaging Earth's plates once they have sunk back into the Earth is very difficult," remarked Wagner, principal investigator of the PULSE Peruvian project. "It's very exciting to see results that tell us more about their ultimate fate, and how the materials within them are slowly reworked by the planet's hot interior. The original fabric in these plates stays stable for so long at the Earth's surface, that it's eye-opening to see how dramatically and quickly that can change."

Lead author of the study, Caroline Eakin of Yale University and the University of Southampton in the U.K., said, "Our findings provide some of the first direct evidence that subducted slabs are not only weaker and softer than conventionally envisioned, but also that we can peer inside the slab and directly witness their behavior as they sink."

Other researchers on the study were Maureen Long of Yale University, Alissa Scire, Susan Beck and George Zandt of the University of Arizona, and Hernando Tavera of the Instituto Geofisico del Perú. ■

(Top) Lara Wagner (right) conducts her fieldwork in numerous locations, including Peru.

(Left) The illustration shows the Nazca Slab subducting, or gliding down into the Earth, and its unusual horizontal stretching.

The National Science Foundation supported this work.

FIRST THREE

CARNEGIE SCIENCE

VENTURE GRANTS AWARDED

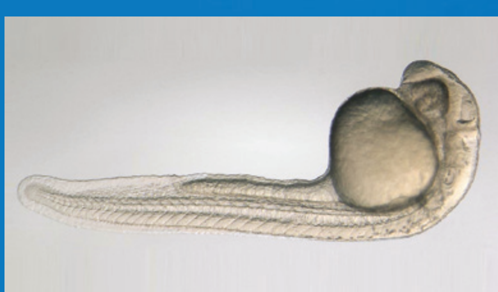
The week of Thanksgiving Carnegie President Matt Scott and Science Deputy Margaret Moerchen announced the first three recipients of the new Carnegie Science Venture Grants. The program, launched this past summer, supports investigations led by Carnegie scientists that ignore conventional boundaries and bring together cross-disciplinary teams to provide fresh eyes for new questions. Each grant provides $100,000 of support.

Sixteen proposals were submitted by the October 8, 2015, deadline. A 13-member internal review panel had the difficult job choosing the first three (of six) projects.

The belief is that these projects will grow in unexpected ways with many surprises. Congratulations to the recipients! Future awards will be distributed twice yearly following the proposal and review process in April/May and October/November.

Steve Farber

Wolf Frommer



Zebrafish are clear when young (above) and are ideal for observing metabolic processes in real time.

Adult zebrafish image courtesy International Institute of Molecular and Cell Biology

1

Wolf Frommer of Plant Biology and Steve Farber of Embryology

will be studying the SWEET sugar transporter, identified by Frommer in plants, in the Farber lab's zebrafish. SWEET transporters play several key roles in plants, including nectar production and transporting sugars from the leaves to other tissues. This new project will observe their role in animals.

Anat Shahar

Erik Hauri

Steve Elardo

2 Anat Shahar of the Geophysical Lab and Erik Hauri of Terrestrial Magnetism with postdoctoral associate Steve Elardo

will explore the carbon isotope ratios of Earth's mantle. Remarkably, Earth has signatures different from the other rocky planets. The team will be observing the evolution of isotope ratios in a high-pressure environment and analyzing samples in the lab using the nanoSIMS instrument, a highly sensitive ion microprobe.

Earth image courtesy NASA

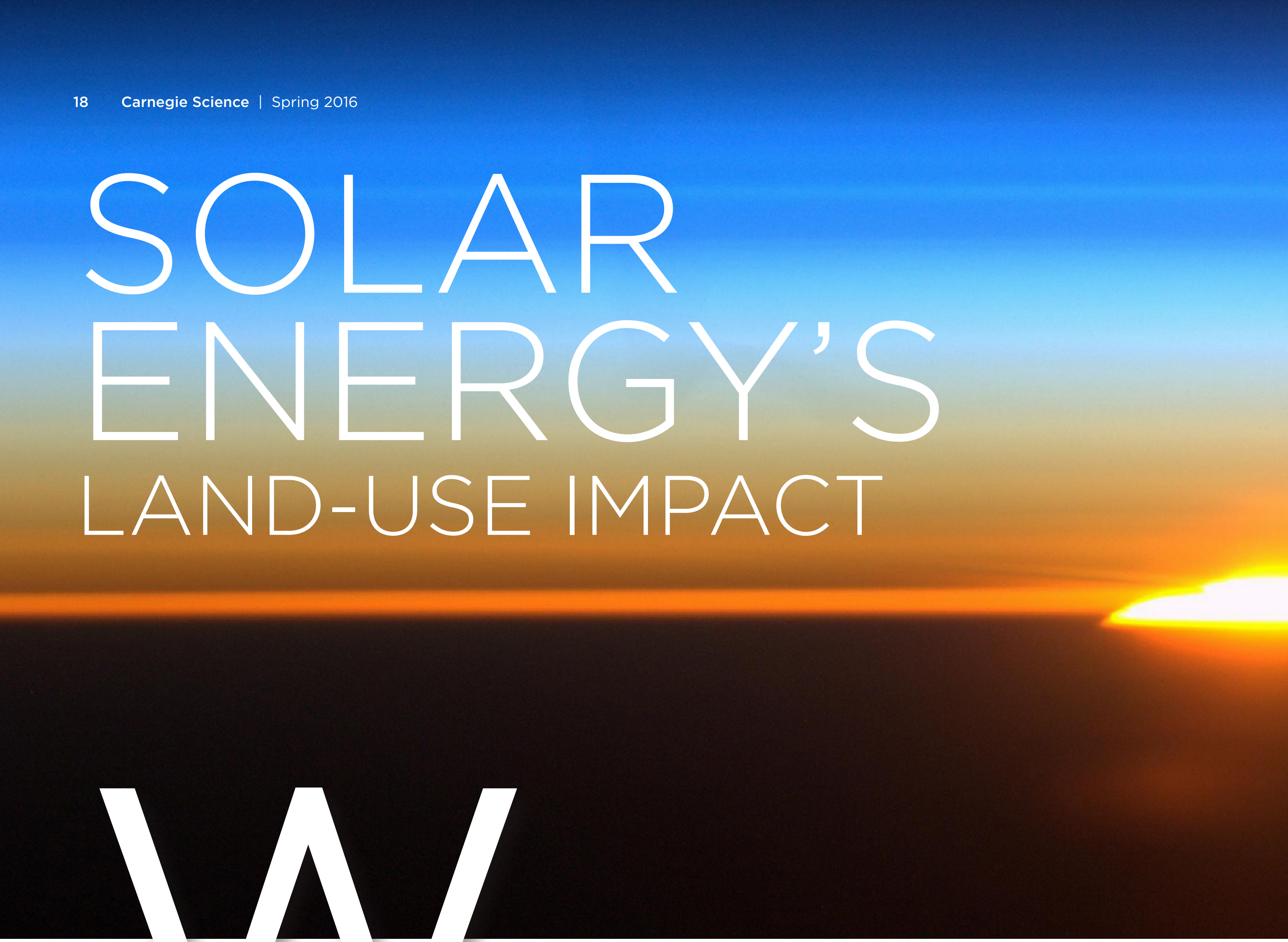
3 Ken Caldeira's and Greg Asner's teams, both of Global Ecology,

will use Asner's unique remote-sensing capabilities to map coral bleaching off the coast of Hawaii in combination with in situ studies of coral biology performed by the Caldeira lab. The objective is to see the effect of climate change on the population and diversity of the coral.

Greg Asner

Postdoctoral associates Rebecca Albright (top) and Robin Martin (bottom) are team members on the grant.

Ken Caldeira snorkeling.



SOLAR ENERGY'S LAND-USE IMPACT

With mounting vigor for combating global climate change, increasing the use of renewable energy resources such as solar, without compromising natural habitats, is a challenge to the traditional model of utility-scale solar energy installations. Such facilities use vast swaths of land for solar-gathering and energy-generating equipment. Until now, studies quantifying the effects on land-cover change and analyses of impacts on protected areas near solar facilities have been limited.

New work by former Carnegie Ph.D. student Rebecca R. Hernandez (now a postdoc at U.C.-Berkeley and Lawrence Berkeley National Laboratory) and Carnegie colleague Madison K. Hoffacker (now at U.C.-Riverside's Center for Conservation Biology) assessed the siting impacts of 161 existing, under construction, and planned utility-scale solar energy facilities in California. The researchers published their results in the *Proceedings of the National Academy of Sciences*. Utility-scale solar energy facilities generate at least 1 megawatt, which is enough to power approximately 165 homes. The team found that a majority of sites are located in natural California shrub- and scrublands covering about 145 square miles (375 km^2); 28% are in croplands and pastures, less than 15% are in developed areas, and some 19% are in areas far from existing transmission infrastructure, which has adverse economic, energetic, and environmental consequences.

This study included two kinds of solar technologies: photovoltaics (PV), which use semiconductors, and concentrating solar power (CSP), which use mirrors to focus the Sun's rays for generating steam. Previous work by Hernandez and colleagues found that these technologies in built-up areas could meet California's energy demands three to five times over.

"California, as an early adopter of solar energy, is a model system for understanding the complex siting decisions made by all parties—from developers to governmental agencies, to stakeholders and communities—involved in utility-scale solar energy development," remarked Hernandez. "Solar energy in developed areas, or for example on contaminated lands, would have great environmental co-benefits, but this is not what is being emphasized. Instead, we see that 'big solar' is competing for space with natural areas. Knowing this is vital for understanding and creating predictions of a rapidly changing global energy landscape."

Large-scale, utility solar energy facilities use vast areas of land for solar-gathering and energy-generating equipment. Until this study led by Rebecca Hernandez, information quantifying the effects on land-cover change and analyses of impacts on protected areas near solar facilities was limited.

Rebecca Hernandez was a Ph.D. student in Chris Field's lab when she did this work. She is now a postdoctoral fellow at U.C. -Berkeley and the Lawrence Berkeley National Laboratory.
Image courtesy Robin Kempster

In analyzing impacts on protected areas, the researchers calculated the proximity of solar installations to them. The fact that nearly 20% of solar facilities were greater than 6 miles (10 km) from transmission infrastructure means that the energy must travel farther and will therefore have greater energy losses. They cost more to build, and new transmission corridors degrade the natural environment.

Almost 30% of all installations were in croplands and pastures. "We were struck by this finding too," Hernandez stated. "We are seeing landowners, particularly in the Central Valley, shift from harvesting crops and foraging to harvesting the Sun."

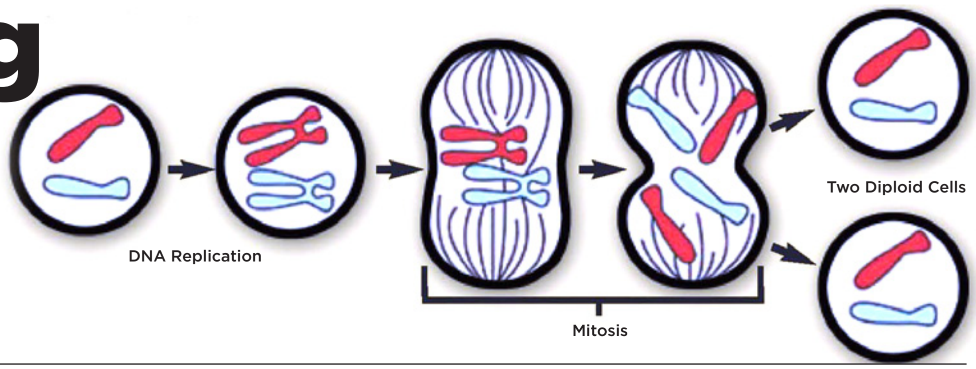
After evaluating land-cover change from solar facilities, the researchers used the Carnegie Energy and Environmental Compatibility computer model to develop a compatibility index to identify areas of potential and direct conflict, with respect to environmental resources California-wide. Compatible areas are areas that are already developed. For photovoltaic technology, they identified some 8,500 square miles (22,028 km^2) of these compatible areas (11.2% of total PV installations) and 30,000 square miles (77,761 km^2) of potential compatible areas (71.7% of PV installations). Potentially compatible areas are the next best thing. They are not protected, they would not require heavy site preparation, and they are within 6 miles (10 km) of transmission lines and roads. Incompatible areas are natural and protected areas. The scientists found that some 55.5% of CSP installations were in either compatible or potentially compatible areas.

Hernandez explained, "If our country wants to reduce greenhouse emissions by 80% of 1990 emissions by 2050, some 27,500 square miles (71,428 km^2) of land could be required for solar installations, which is about the area of South Carolina. We can increase the land-use efficiency in ways such as decreasing spaces between rows of photovoltaic modules or concentrating solar power mirrors. Better yet is to locate installations in areas already affected by humans, such as on landfills, over parking lots, and on rooftops and nearest to where the energy is being consumed."

Kara Moore, an applied ecologist at the Center for Population Biology at U.C.-Davis who has conducted landmark experimental studies on effectiveness of rare species mitigation within a utility-scale solar energy facility stated, "This study gives policymakers clear guidance on the great potential we have to site utility-scale renewable energy more sustainably by building it into our existing human-affected landscapes. By doing so we benefit by simultaneously increasing the efficiency of renewable energy systems and by avoiding unnecessary impacts to our precious remaining natural areas." ■

The McGee Research Grant of the Stanford's School of Earth Sciences, the TomKat Center for Sustainable Energy, the Jean Langenheim Research Fellowship of Graduate Women in Science Society, the Hispanic Scholarship's Fund's William Randolph Hearst Fund Scholarship, and the Vice Provost Office of Graduate Education's Diversifying Academia Recruiting Excellence Program supported this work. Other authors are Michelle Murphy-Mariscal, Grace Wu, and Michael Allen.

Decoding Cell Division



In this simplified diagram of mitosis, the chromosomes (red and blue) inside a cell nucleus duplicate to produce two daughter cells, so-called sister chromatids. The sisters separate with the help of rope-like fibers for the cell to divide into two. Each new cell has a complete set of genetic information.

Every high school biology class learns about the tiny cells that our bodies are made of and the diverse actions that they perform. One of these actions is called mitosis, the series of steps through which a cell divides itself into two daughter cells, each of which has the same genetic material. Mitosis involves copying or "replicating" each of the cell's DNA-containing chromosomes and then separating them so that each of the two newly created cells has a complete set of chromosomes. Since each chromosome carries distinct genes the daughter cells need all of them, but it is damaging for the daughter cell to have too many of any of them.

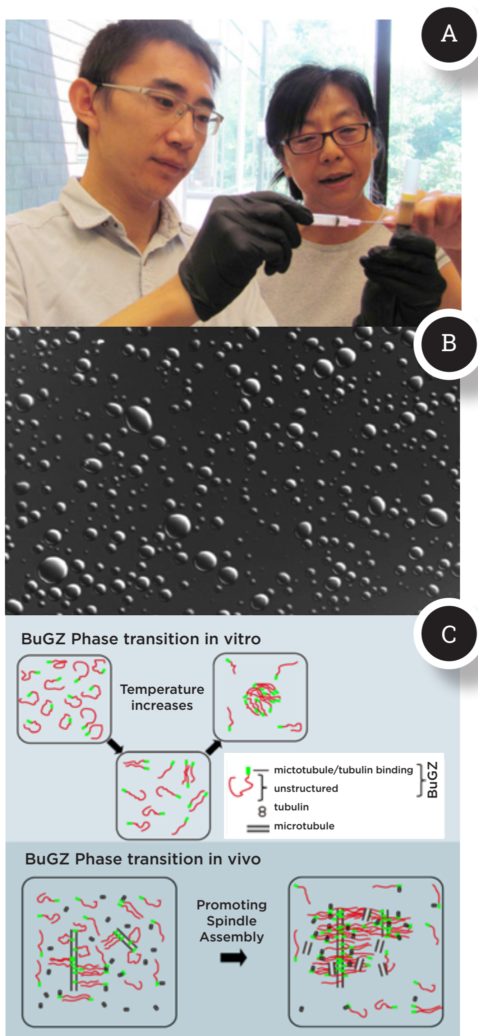
Errors in mitosis can lead to cancer and other diseases, so understanding every detail of cell division is of great interest. New work from a team led by Carnegie's Yixian Zheng, now acting director of the Department of Embryology, zeroes in on the protein called BuGZ. Published in *Cell*, the team's findings show that BuGZ supports the assembly of essential cell components called the spindle matrix and microtubules.

Chromosome separation is facilitated by the spindle, a framework composed of interconnected fibrous microtubules. The two copies of each chromosome are attached to the spindle's microtubule fibers and then moved apart to opposite sides of the dividing cell with the help of the spindle and its microtubule fibers. Each of the two daughter cells receives one complete copy of the genetic material. Besides the microtubule fibers, the spindle also contains other materials that are visible under the electron microscope. These poorly understood materials are referred to as the spindle matrix and are believed to be important for cell division.

The team found that under spindle assembly conditions, many copies of the BuGZ protein condense along the microtubule fibers to form droplets. This condensation occurs because molecules of the BuGZ protein can assemble with each other, referred to as phase transition. During mitosis, these condensed BuGZ droplets promote the assembly of the spindle matrix, which makes additional microtubule fibers and links the fibers together, thereby promoting assembly of the spindle itself.

The formation of BuGZ droplets is the result of an evolutionarily ancient water-repelling (hydrophobic) segment of BuGZ, which rejects interaction with the surrounding cellular fluid. Instead BuGZ proteins self-associate into these "inward-looking" droplet shapes. The team found that several other proteins found in the spindle matrix in both frogs and fruit flies have segments that resemble the water-repelling portion of BuGZ. They speculate that the whole spindle matrix could be formed through self-association of the hydrophobic segments of these proteins. This could help explain why many seemingly unrelated proteins make up the spindle matrix, which has been one of the central mysteries of the cell division process.

"Because BuGZ is evolutionarily conserved and found in both vertebrates and invertebrates, our findings should open the door to further research on spindles and their matrices in a wide variety of organisms," Zheng said. ■

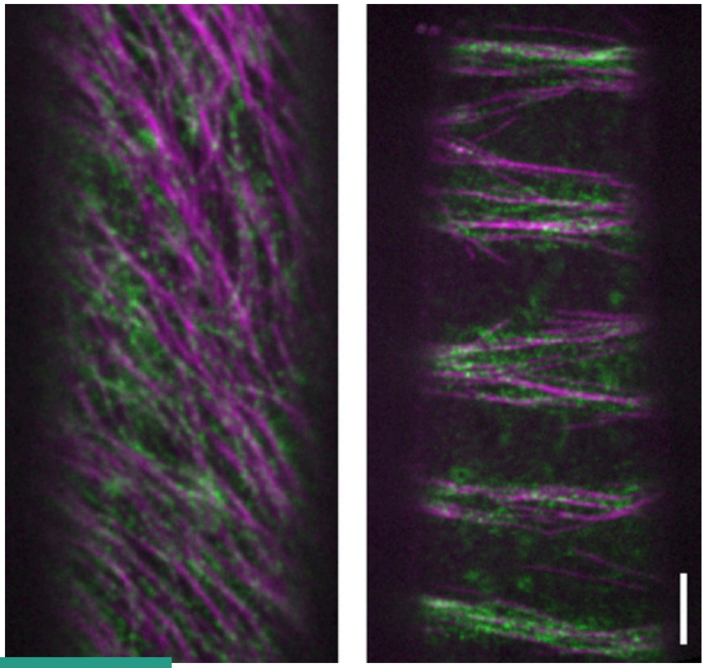


Concentrated cell destruction can be made by spinning the mature frog eggs *(Xenopus)* in a centrifuge without a buffer, which crushes and stratifies the cell contents. The stratified golden layer above the needle shown in panel A, where Yixian Zheng is pointing, is an undiluted cell "lysate," which supports many reactions found in cells including the assembly of the spindle apparatus. This system has allowed the investigators to discover a spindle matrix protein called BuGZ that uses its self-association droplet-forming property shown in panel B to support the assembly process of the spindle and its matrix as depicted in panel C.

Images courtesy Yixian Zheng and Hao Jiang

The Chinese Academy of Sciences, the Ministry of Science and Technology of China, the National Science Foundation of China, and the U.S. National Institutes of Health supported this work. Zheng's coauthors were Carnegie's Hao Jiang (lead author, also of the Chinese Academy of Sciences), Shusheng Wang (co-lead author), and Yuejia Huang; Xiaonan He and Xueliang Zhu of The Chinese Academy of Sciences; and Honggang Cui of The Johns Hopkins University.

NEW WAY TO WATCH PLANT-CELL WALLS ASSEMBLE



The pervasive plant fiber cellulose, which makes up cell walls, represents most of the biomass on Earth. It is used to create everything from textiles and building materials, to renewable biofuels. Primary cell walls determine the shape of the plant, while secondary cell walls—most of the cellulose—are laid down later to strengthen the structure and vascular system that transports water and nutrients.

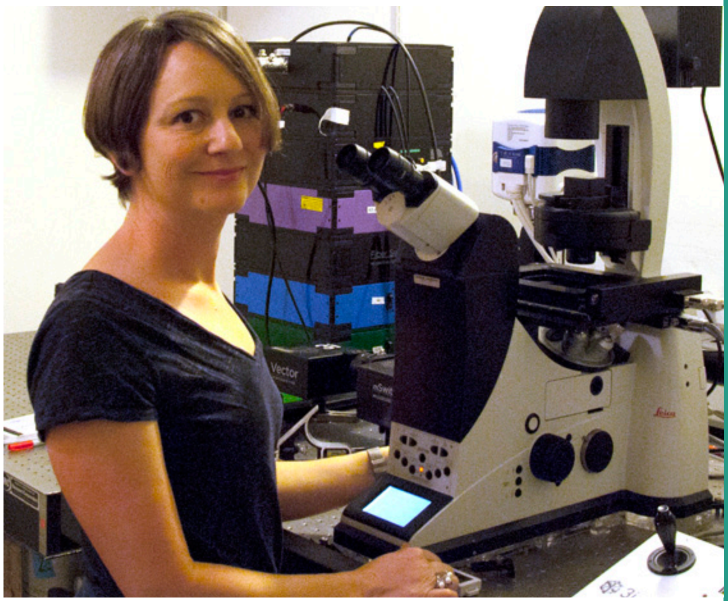
Now scientists, including Carnegie's David Ehrhardt and Heather Cartwright, have exploited a new way to watch the trafficking of the proteins that make cellulose while forming cell walls in real time. They found that the organization of this trafficking by structural proteins called microtubules, combined with the high density and rapid rate of these cellulose producing enzymes explains how thick and high-strength secondary walls are built. This basic knowledge helps understand how plants can stand upright, which was essential for the movement of plants from the sea to the land, and may be useful for engineering plants to increase yields or to produce novel bio-materials. The research was published in *Science.*

The live-cell imaging was conducted at Carnegie with colleagues from the University of British Columbia (UBC) using customized high-end instrumentation. For the first time, it directly tracked cellulose production to observe how xylem cells, cells that transport water and some nutrients, make cellulose for their secondary cell walls. Strong walls are based on a high density of enzymes that catalyze the synthesis of cellulose (called cellulose synthase enzymes) and their rapid movement across the xylem cell surface.

Watching xylem cells lay down cellulose in real time has not been possible before, because the vascular tissues of plants are hidden inside the plant body. Lead author Yoichiro Watanabe of UBC applied a system developed by colleagues at the Nara Institute of Science and Technology to trick plants into making xylem cells on their surface. The researchers fluorescently tagged a cellulose synthase enzyme of the experimental plant *Arabidopsis* to track the activity using high-end microscopes.

"For me, one of the most exciting aspects of this study was being able to observe how the microtubule cytoskeleton was actively directing the synthesis of the new cell walls at the level of individual enzymes. We can guess how a complex cellular process works from static snapshots, which is what we usually have had to work from in biology, but you can't really understand the process until you can see it in action," remarked Ehrhardt. ■

". . . you can't really understand the process until you can see it in action."



(Above) Heather Cartwright is the core imaging director at the Department of Plant Biology.

(Above left) These freeze-frames of the imaging process show a plant primary cell wall on the left and the secondary cell wall on the right. Plant microtubules are shown in magenta, while cellulose synthase (CESA) enzymes are in green. The scale bar is 5 micrometers.

Image courtesy Heather Cartwright

SWEETS Get Sweeter 'n' Sweeter

Wolf Frommer

Some time ago Carnegie's Wolf Frommer and collaborators identified a unique class of sugar-transport proteins, called SWEETs, in plants. These proteins play key roles, such as producing nectar, exporting energy manufactured in the leaves to the other plant organs, and filling seeds with nutrients to feed an embryo. In three recent papers Frommer and colleagues delved into the inner workings of two members of this family, SWEET2 and SWEET4. The teams unraveled the molecular structure of SWEET2, a transport protein that plays a critical role in limiting the sugar supply available to root microbes to the correct level. In another discovery, he and collaborators found that a sugar-transport protein in maize and rice called SWEET4 is necessary for successful seed filling and shows genome changes that indicate domestication by humans.

SWEET2

Like humans, plants are closely associated with microbes. The majority of these microbes are beneficial, but some cause disease. Maintaining the balance is critical. Plants feed these microbes, and it's thought that they do so just enough to allow the good microbes to grow and to prevent the bad ones from gaining strength. This microbe feeding is mediated by sugar-transport proteins.

One team, led by the Stanford's Liang Feng, discovered the molecular structure of a SWEET2 transporter from rice. That discovery, combined with determining the crucial amino acids necessary for the protein to function, is the key to figuring out the mechanism by which it works. That is important for understanding what happens when the transporter fails from disease or pathogens and for learning how to protect against these risks.

This is the first time the structure of a member of the SWEET class of proteins has been described, and it is only one of three structures understood so far for sugar transporters in animals and plants.

Another team—on which Frommer worked with then-Carnegie postdoc Woei-Jiun Guo and Dorothea Tholl of Virginia Tech—focused on SWEET2's role in protecting the mustard plant *Arabidopsis* from parasitic infection. They showed that SWEET2 helps stockpile sugars in a storage bubble inside of plant cells called the vacuole, thereby limiting the sugar supply to feed only the good microbes at a level that prevents the growth of the bad microbes.

The team showed that SWEET2 facilitates the retention of sugar in roots, which could be a mechanism of starving and resisting pathogens living in the immediate surroundings. They found that SWEET2 expression was increased 10-fold during an infection with the *Pythium* parasite and that specially created mutants lacking SWEET2 were more susceptible to the parasite.

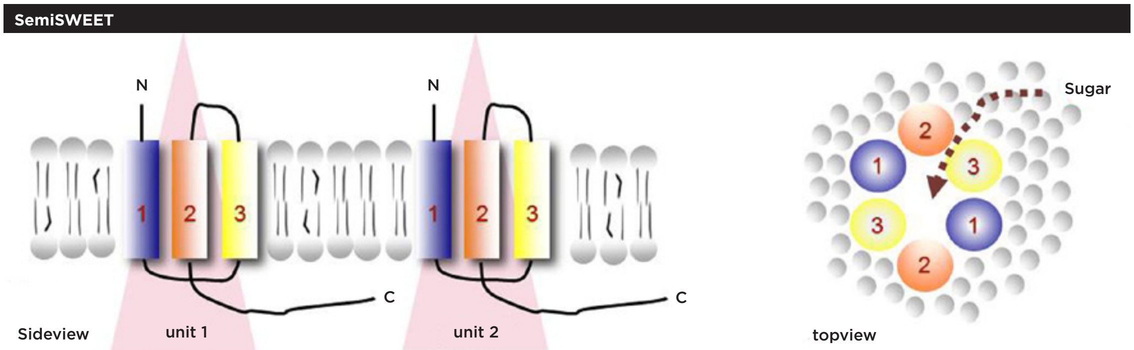
SWEET4

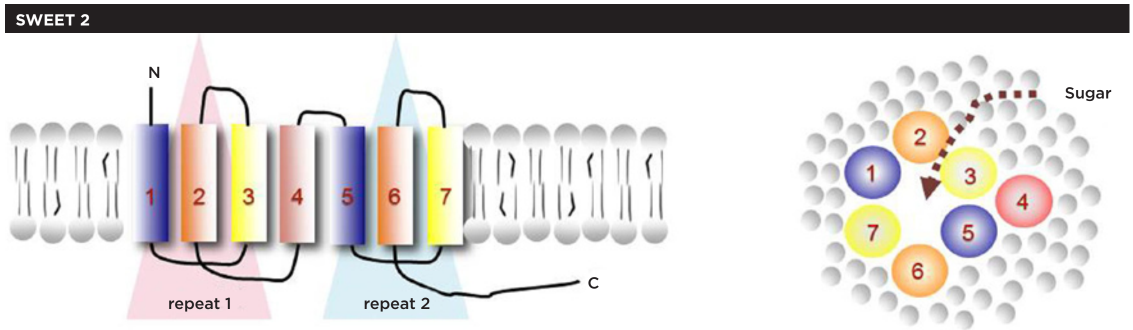
Once a mother plant releases its embryos to the outside world, they have to survive on their own. To ensure success, the mother plant provides the embryo with a backpack full of energy called the endosperm. The mother plant produces sugars in its leaves when it turns the Sun's energy into chemical energy; it then transports the energy to the seeds stored in these backpacks. The amount of sugars that fill a seed directly determines the seed's size.

The plant endosperm has been an important factor in crop plants, which have evolved larger backpacks. Over time, people simply selected plants with large backpacks. This human-driven evolutionary selection happened with all of our crop plants as wild plants were converted into more and more useful and nutritious versions. Using modern molecular genetic methods, scientists can now see which gene variants were in fact being selected during this domestication process.

Frommer and Feng had previously worked together to determine the structure and mechanism of the bacterial analog to SWEET transporters, called SemiSWEETs. It had been predicted that SWEETs arose by a doubling and fusion of SemiSWEET genes during evolution. The similarities they found between the structural folds of SemiSWEET and SWEET2 strongly support this theory. Above, you can see the two identical protein units (units 1 and 2) that associate with each other to create the SemiSWEET transport pore through which sugar passes through the cell membrane. Below you can see how the two units are fused together by an additional element (4) to form a single protein (1 through 7)—rather than two separate, associated proteins, as is found in the bacterial version.

Images courtesy Wolf Frommer





(Left) Sugars are manufactured in the leaves, when the plant turns the Sun's energy into chemical energy, and are then transported to the seeds. The amount of sugars that fill a seed directly determines the seed's size. The ancestors of modern maize had much smaller endosperms. It is thought that seed sizes were increased by the selective pressures of agricultural domestication. Larger, more sugar-filled seeds such as maize kernels were more attractive to human cultivators, due to their nutritive value and their ability to produce sturdier seedlings.

Images courtesy of Davide Sosso, lead author of this study

SWEET Domestication

The ancestors of the modern maize plant had much smaller endosperms. It has long been thought that seed sizes, for many types of grains, were increased by the selective pressures of agricultural domestication. Larger, more sugar-filled seeds such as maize kernels were more attractive to human cultivators, due to their nutritive value and their ability to produce sturdier seedlings. But a direct link between the biochemistry of the seed-filling processes and domestication had long remained elusive.

Frommer and colleagues discovered that the sugar-transport protein in maize and rice, SWEET4, is both necessary for successful seed filling and shows genome changes that indicate domestication by humans.

Several labs contributed to the SWEET4 work. Frommer's team analyzed maize genes to find ones that were "turned on" during seed development. Prem Chourey's group at the University of Florida showed that the gene SWEET4c, which encodes a sugar transporter protein in maize, is specifically expressed in the maize seed.

The evidence that the SWEET4c gene was selected during domestication was discovered by the team of Jeff Ross-Ibarra at U.C.-Davis, while comparing SWEET4 sequences from modern maize against its wild ancestor *Teosinte*. The team found that SWEET4c becomes highly active—meaning it is producing SWEET4c protein—right at the time when import of sugars into a seed is maximal, between 10 and 17 days after the seed is pollinated.

A major breakthrough of this study was finding that SWEET4c is absolutely essential for seeds to be filled. Without a working version of the gene encoding SWEET4c, such as in the mutant lines provided by the UniformMu resource (Don McCarty and Karen Koch at the University of Florida), sugars were not delivered to the seeds and the backpack was empty.

The authors found that the corresponding gene in rice was also critical for seed filling and showed independent signs of selection by farmers and breeders. ■

Variations of the SWEET family of sugar transporters are patented or patent-pending.

Some SWEET work was supported by Stanford University; the Harold and Leila Y. Mathers Charitable Foundation; the Alfred P. Sloan Foundation; National Natural Science Foundation of China; the Division of Chemical Sciences, Geosciences, and Biosciences' Office of Basic Energy Sciences (BES) at the U.S. Department of Energy (DOE); the National Science Foundation (NSF); and the NSF Postdoctoral Research Fellowship in Biology. Part of this work was based upon research conducted at the Advanced Photon Source (APS) on the Northeastern Collaborative Access Team, which are supported by a grant from the National Institute of General Medical Sciences from the National Institutes of Health. Use of the APS, an Office of Science User Facility operated for the U.S. DOE and the Office of Science by Argonne National Laboratory, was supported by the U.S. DOE. Other SWEET work was supported by the Ministry of Science and Technology Taiwan, the U.S. DOE's Office of BES, the NSF, and the U.S. Department of Agriculture National Institute of Food and Agriculture.

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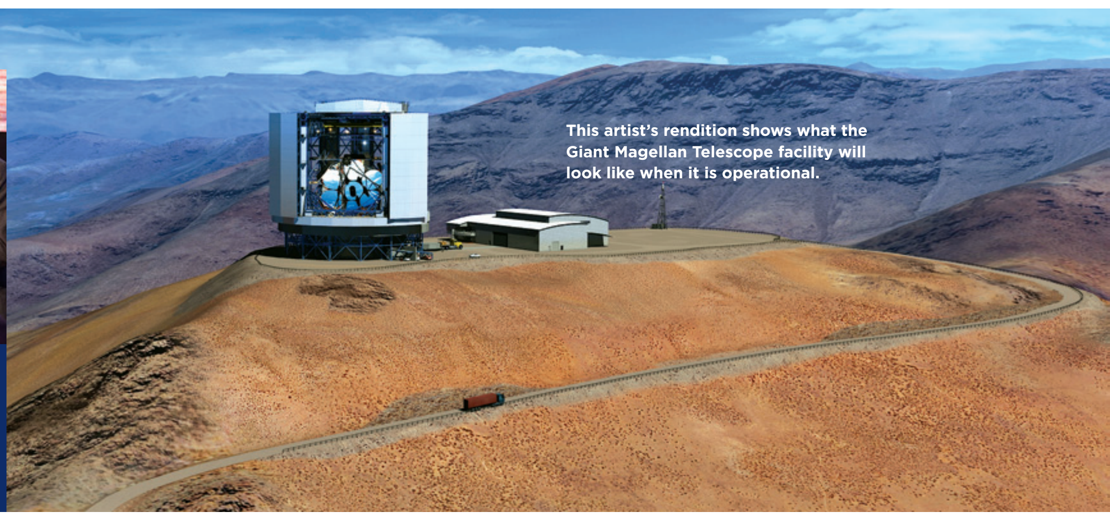
Chilean president Michelle Bachelet (left) attended the Giant Magellan Telescope groundbreaking ceremony. Former director of the Las Campanas Observatories, Miguel Roth (right), presided over the celebration.
Images courtesy Giant Magellan Telescope Organization



This artist's rendition shows what the Giant Magellan Telescope facility will look like when it is operational.

The Giant Magellan Telescope Breaks Ground at Las Campanas

On November 11, 2015, scientists, senior officials including Chilean president Michelle Bachelet, and supporters from an international consortium of universities and research institutions gathered on a remote mountaintop at Carnegie's Las Campanas Observatory in the Chilean Andes to celebrate the groundbreaking for the Giant Magellan Telescope (GMT). The ceremony marked the beginning of on-site construction of the telescope and its support base. The GMT is poised to become the world's largest telescope when it begins early operations in 2021. It will produce images ten times sharper than those delivered by the Hubble Space Telescope and will address key questions in cosmology, astrophysics, and the study of planets outside our Solar System.

Construction crews will soon be busy on the site building the roads, power, data, and other infrastructure needed to support the observatory.

The unique design of the telescope combines seven of the largest mirrors that can be manufactured, each 8.4 meters (27 feet) across, to create a single telescope effectively 25 meters or 85 feet in diameter. The giant mirrors are being developed at the University of Arizona's Richard F. Caris Mirror Laboratory. Each mirror must be polished to an accuracy of 25 nanometers or one millionth of an inch.

The GMT will enable astronomers to characterize planets orbiting other stars, witness the early formation of galaxies and stars, and gain insight into dark matter and dark energy. The GMT's findings will likely give rise to new questions and discoveries.

The GMT Organization board of directors officially approved the project's entry into the construction phase in early 2015 after the eleven international founders committed over $500M towards the project. Founders come from the U.S., Australia, Brazil, and Korea, with Chile as the host country. ■

The Giant Magellan Telescope Organization (GMTO) manages the GMT project on behalf of its international partners: Astronomy Australia Ltd., the Australian National University, Carnegie Institution for Science, Fundação de Amparo à Pesquisa do Estado de São Paulo, Harvard University, Korea Astronomy and Space Science Institute, Smithsonian Institution, Texas A&M University, the University of Arizona, the University of Chicago, and the University of Texas at Austin.