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Engineering & Science

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Travel through space and time with Caltech's scientists

VOLUME LXXV, NUMBER 2, SUMMER 2012

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VOLUME LXXV, NUMBER 2, SUMMER 2012

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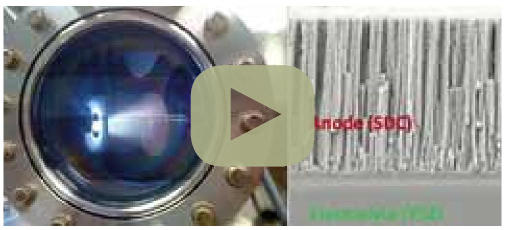

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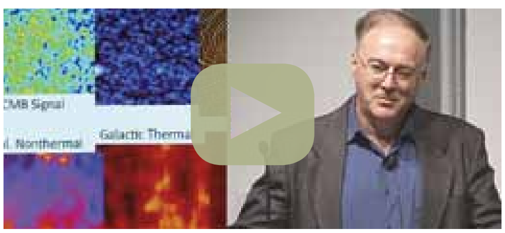

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Guest Editor
Lori Oliwenstein

Managing Editor
Doreese Norman

Contributing Writers
Kimm Fesenmaier, Binti Harvey, Katie Neith, Kathy Svitil, Ann Wendland, Marcus Y. Woo

Copy Editor
Michael Farquhar

Art Director
Jenny K. Somerville

Staff Artist
Lance Hayashida

Design and Layout
Etch Creative

Business Manager
Rosanne Lombardi

The California Institute of Technology
Brian K. Lee—*Vice President for Development and Institute Relations*

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FROM THE PRESIDENT

Dear alumni and friends of Caltech,

June means commencement, a key milestone in our students' journeys as scientists, engineers, citizens, educators, entrepreneurs, and leaders.

A life in science and technology is a journey with endless frontiers—not just intellectually, but geographically. Scientific investigation happens not just in labs or classrooms, but in the world around us. Which is why this issue of E&S focuses on the experiences of some of Caltech's most intrepid explorers, who are taking to the seas, traveling to the remotest regions of our planet, and searching the galaxy in their continual quest to expand human knowledge.

But these sorts of voyages—as fellow travelers know from experience—can come with a hefty price tag. That's why Caltech is so grateful to donors such as Foster and Coco Stanback, whose ongoing and passionate support has given and will continue to give our scientists the freedom to explore innovative fields of study and to pursue discoveries that might otherwise be impossible to realize.

The work described in this issue alone provides rich examples of the Stanbacks' crucial investments in our people and our mission. Their significant gift to the Discovery Fund for Planetary Science has benefited geologist John Grotzinger, the lead scientist for the Mars Science Laboratory (see "Mission to Mars," page 12); the work done by geologist Michael Lamb (see "Field Notes," page 27) is funded in part by the Terrestrial Hazard Observation and Reporting Center, or THOR, which was created by the Stanbacks; and one of the postdocs working with geochemist Alex Sessions (see "Anchors Aweigh," page 20) is a Stanback Postdoctoral Scholar.

Such generosity and partnership send a clear message to our students that their journey of discovery is only beginning, and the best is yet to come. My hope for every student is that they carry the Caltech values of curiosity and passion for science into the far corners of the world and even the universe, confident that they are indeed the next generation of pioneers, inventors, and entrepreneurs.

"Such generosity and partnership send a clear message to our students that their journey of discovery is only beginning, and the best is yet to come."

Yours in discovery,

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Random

The Wright Way: Fred Culick—Caltech's Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Professor of Jet Propulsion, Emeritus—has pretty much always had an obsession with airplanes. They have influenced not only his personal but also his professional life: he's an aeronautical historian, an applied physicist, and a JPL researcher who draws, builds, studies, and flies planes in his free time. "Airplanes and flying are among the most vivid of my earliest memories of Camden, Maine, where I lived the first six years of my life," says Culick, who as a young child watched his neighbor build and fly large model planes. "I owe a lifelong debt to that man next door because my early love of airplanes has been a lasting influence."

In 1979, Culick started working on the Wright Flyer Project, an initiative of the Los Angeles section of the American Institute of Aeronautics and Astronautics to build and test a replica of the Wright Brothers' *Flyer*—the powered, controllable aircraft that ushered in the era of flight in December 1903.

Today, he's chairman and chief engineer for the project, which has been testing a model of the *Flyer* in wind tunnels since the mid '80s and has now nearly completed a second full-scale copy; the team hopes to fly it later this year over Southern California. The plane (seen here in its hangar at Flabob Airport in Riverside, California) is not just being built as a flight of fancy. If it leaves the ground successfully, it will mark the first time since 1903 that a *Flyer* has actually taken to the air, and Culick plans to be the test pilot for its inaugural flight. After over 30 years of planning, all he needs is the Wright stuff. —*KN* E&S

If you have any images you would like to share with us, go to EandS.caltech.edu for more information.

Walk

THINGS THAT CAUGHT OUR EYE . . .

A LOVE LETTER TO CALTECH

FROM A CALTECH MOM

When our Caltech graduate talks about her job as a research physicist, my husband and I feel pride and joy. But looking back at her childhood, not every day was so joyful, as many parents of Caltech students and graduates know.

Early on, I discovered I knew very little about the painful disconnect that sometimes exists when a bright child unintentionally kicks her thinking skills into overdrive. By the time my daughter was four, it was apparent that the neighbor kids liked her but didn't want to invite her over much. Her adultlike conversation, imagination, and out-of-the-box interests often confused them and didn't fit into their world.

Fortunately, by her teens our daughter had come to know a few other "smart" girls in public school who shared some of the same interests. With plenty of hugs from our family, and some inspiring teachers, our child survived adolescence, graduated, and decided on Caltech—and so begins my love letter. Having seen all the emotional bumps and bruises that exceptional kids get just trying to enjoy childhood, I hoped the "grown-up" college environment would make her a happier person. Well boy, howdy, were my prayers ever answered!

We expected and got the "This-is-too-hard-I-want-to-quit" semester. But what we didn't expect was the outrageous, and utterly delightful, Caltech *playtime* that is the signature of this school. Caltech students not only become our future professional engineers, scientists, and inventors, but *profess and create the future with their fearlessly engineered and scientifically inventive . . . play.*

Where else but Caltech can one toss nitrogen-frozen pumpkins, play hide-and-seek with a car (expertly dismantled and reassembled in a closet), and gleefully calculate how to shoot oranges into the next county?

These come-out-and-play games of creative engineering and discovery are, like all good play, challenging, mind-expanding, and exactly what smart people need, in an environment of relative safety and freedom. This is the kind of play our children have hungered a lifetime for, to learn, and to grow, and to figure out unexpected ways to create, repair, heal, and solve problems.

Then, when we visited campus for the first time, we found our daughter talking with some other students who were definitely including her. She was smiling a kind of smile I had not seen in years . . . a sweet, comfortable smile, and the other students shared that *same expression*. I knew she was in a more adult, accepting crowd. It occurred to me that these were all someone else's *kids* who were also, finally, getting a chance to be *themselves*. I wanted to hug them all.

My husband and I are so glad our daughter stayed on to graduate from Caltech. She received a priceless gift there. Not only did she receive an outstanding education, but she found lifelong friends who were carefully discovered by Caltech and encouraged to play the "Caltech way." They all *finally* learned, through losing and winning games of discovery, imagination, self-control, and silliness, the experience and wisdom they needed to work through life as full-fledged grownups.

And for that, Caltech, I think I love you.

As Caltech's class of 2012 readies itself for the Institute's 118th commencement, its seniors are casting glances back over their undergrad years, and looking forward into their future:

Copresident of the senior class **KATIE BRENNAN** has taken full advantage of Caltech's funding and scholarship opportunities. *"Apply for everything,"* is Brennan's succinct advice to current and future Techers. *"There are amazing funds, scholarships, and awards you can apply for, and they are unique to Caltech."*

As chair of the Interhouse Committee—the student-life council made up of the presidents of all the houses—**LAURA CONWILL** has had a chance to look at Caltech's social dynamics. *"The houses are independent social communities,"* she notes, *"but anybody can really go and hang out in any one of them. You probably form more lasting friendships in this environment than you would at a larger school."*

MYTHILI IYER has been a Caltech-Occidental Concert Band member, the Fleming House treasurer, and the business manager of the Big T. *"I've had the most fun when I've given myself the opportunity to do things outside of academics,"* she admits. *"It was really difficult sometimes to commit to even just two hours a week of practice, but setting that time aside has really helped."*

ARVIND KANNAN will be attending the University of Cambridge next year, working toward a Master of Philosophy in chemistry as a Churchill Scholar. *"People come here because they have a passion for science, for technology, for understanding the world around us,"* he says. *"I think the people who really succeed here are those who keep that at the forefront of everything they do."*

MATCH THE DIAGRAM TO THE DISCOVERY

Richard Feynman revolutionized not only the practice of physics but also its language when he began using diagrams to represent his formulation of quantum electrodynamics (QED). Physicists quickly found that the diagrams simplified long calculations.

The diagrams on this mural—which you can find on the newly renovated fourth floor of the Downs-Lauritsen Laboratory—depict discoveries made over the years by Caltech's high-energy physicists. Here are the stories behind a few; can you find their corresponding diagrams? (See answers at bottom of page 9.) —*AW* E&S

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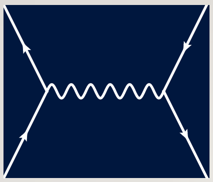

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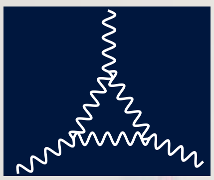

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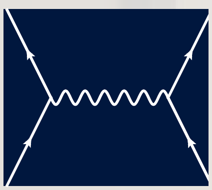

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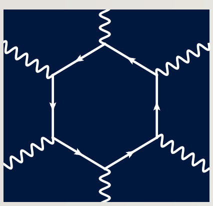

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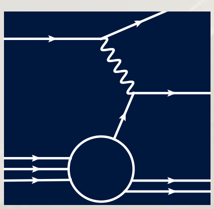


1. Feynman introduced his Nobel Prize–winning view of QED at the Pocono Conference of 1948, using this diagram to describe how two electrons approach one another, exchange a photon, and then scatter.

2. The discovery by physicist Carl Anderson (BS '27, PhD '30) of the positron—an electron's antiparticle—was actually the first empirical proof of the existence of antimatter, and won Anderson the Nobel Prize in Physics at age 31. This diagram depicts the scattering of an electron and a positron.

3. Nobel Prize–winning theorist Murray Gell-Mann and grad student George Zweig (PhD '64) independently proposed the existence of quarks—the fundamental building blocks of matter. This diagram shows a high-energy electron scattering off a proton (or another hadron, the type of subatomic particle that includes protons), having changed the proton itself; such scattering, in an accelerator, yields evidence of quarks.

4. The 1984 discovery by John Schwarz, the Harold Brown Professor of Theoretical Physics, of the mechanism depicted in this hexagonal diagram revitalized the then nearly abandoned field of string theory.

5. Richard Chace Tolman Professor of Theoretical Physics David Politzer discovered a principle known as asymptotic freedom, revealing why quarks stay confined in nucleons that make up the atomic nucleus. His work—partially represented by this diagram—showed that quarks' interactions counterintuitively weaken with proximity and increased energy but strengthen with distance, and won him a Nobel Prize.

ANSWERS: 1 = C; 2 = A; 3 = E; 4 = D; 5 = B

PUZZLES AND PRANKS AND DITCH DAYS, OH MY!

THE (COMPANION) CUBE'S ROOT

On a cold mid-December morning at around 4 a.m., a small group of Techers on winter break set out to pull a cross-country prank. They planned to turn the Astor Place Cube, a sculpture in Manhattan, into a companion cube, an object from the popular video game Portal. They had constructed six sheets of fabric—one for each side of the cube, and each measuring eight feet by eight feet. Each sheet was designed to attach to another with Velcro. But it was so cold that the glue holding the Velcro to the fabric lost its stickiness.

Ever the clever problem solvers, the Techers returned on another night—this time, with thousands of staples to keep the Velcro in place. The companion cube stayed up until 1 p.m., long enough for pictures of their handiwork to go viral online.

"Pranking is definitely a great distraction from classroom work," says junior Alexander Mouschovias of the Caltech Prank Club. "It's something different, something fun, and something to de-stress from our heavy workload here." The Prank Club is also always on the lookout for fellow pranksters from other universities, he adds. "We'd love to have more pranking rivals other than MIT." *—MW* e&s

DITCH DAY IS TOMORROW!

Ditch Day is sort of the quintessential Caltech experience—a day when seniors ditch school without warning and leave behind elaborate puzzles, scavenger hunts, and other activities—called "stacks"—for the underclassmen to attempt. "Ditch Day is the last hurrah for seniors," says Shannon Mohler, copresident of the class of 2012. "Once we leave, we'll likely never be able to do something like Ditch Day again."

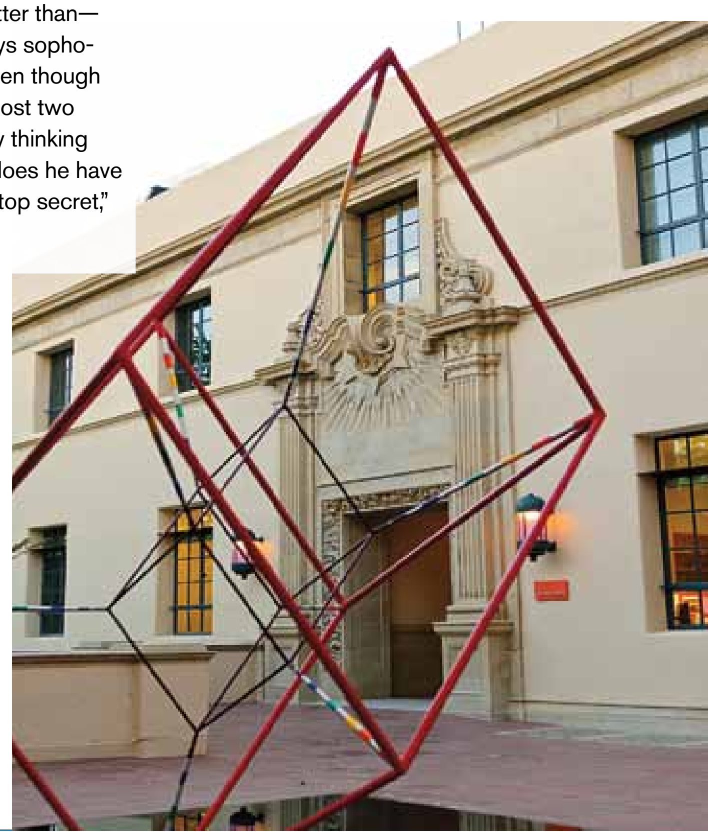
Ditch Day stacks have involved everything from decrypting complex codes to rafting down rivers. One of junior Jimmy Scott's favorite stacks had him melting a lock using a thermal lance—basically a superhot blowtorch—fueled by pure oxygen and . . . bacon.

"Techers see Ditch Day as equivalent to—or better than—Christmas morning," says sophomore Chris Varnerin. Even though his Ditch Day is still almost two years away, he's already thinking about his stack. What does he have planned? "Sorry, that's top secret," he says. *—MW* e&s

PUZZLING PERCEPTION

The newly renovated Linde + Robinson Laboratory houses some of Caltech's most innovative research in environmental science. It also hosts the Institute's most innovative puzzle, positioned just outside the building in the east courtyard. Titled *Perception* and designed by Caltech's Board of Trustees Vice Chair Ronald Linde (MS '62, PhD '64), the sculpture is a treasure trove of scientific symbolism, with references ranging from Earth's axial tilt to dark matter and dark energy. While many of these allusions are spelled out in a statement beside the sculpture, there are some that remain a mystery, and it's up to someone in the Caltech community to find a specific one of them.

The first person to identify the hidden allusion that matches a statement of clues by January 24, 2013, will win $1,000. For the clues and complete contest rules, visit lindecenter.caltech.edu/contest. *—MW* e&s



BY KIMM FESENMAIER

Mission to Mars

Close to midnight on Black Friday, 2011, John Grotzinger was standing in the swampy darkness at Cape Canaveral, snapping photos of an Atlas V rocket, when a car pulled up behind him. "Oh boy," he thought. "This is it . . . I'm getting arrested."

It wouldn't have been your typical arrest: Grotzinger leads the team of scientists that had prepared the precious payload atop that rocket—the Mars Science Laboratory (MSL), the most capable robotic mission ever sent to the Red Planet. Earlier that November day, a colleague had mentioned to Grotzinger that his badge should allow him to get a close-up look at the Atlas V.

And so, after a series of uncertain turns and a bit of off-roading on the beach, Grotzinger found himself in the dark, just outside the fenced-off launch pad, taking in the beauty of the illuminated rocket and steeling himself to be hauled off to jail. He wasn't. The man who drove up behind him that night turned out to be one of the engineers from the Jet Propulsion Laboratory (JPL) who had been at Cape Canaveral doing final checkouts of MSL's car-sized Mars rover, Curiosity. In fact, with his escort and photography privileges, the engineer was able to take Grotzinger right up to the base of the rocket.

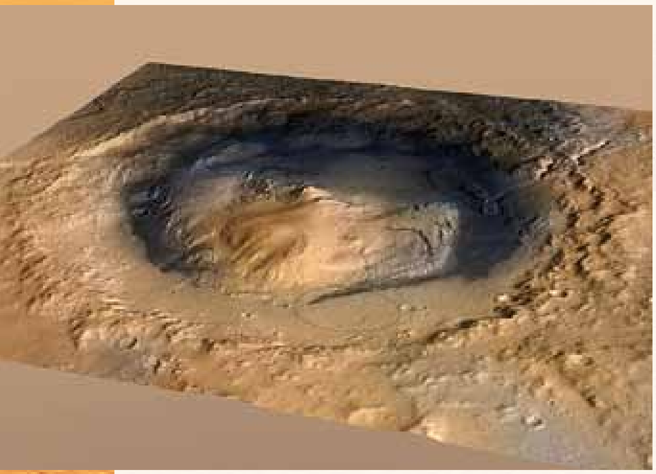
Grotzinger was awestruck. "You get up close and see this enormous thing that you know is going to leave Earth," he says, "and you know all these people have worked on what's inside it, and that this rocket is going to deliver their dreams to the surface of another planet . . . To see it up this close in the dark of night is a reminder of the miracle of engineering, and that we should never take this for granted."

When the rocket blasted off the next morning—sending MSL on its 352-million-mile trip to Mars—Grotzinger was cheering with the science team in the bleachers at the Banana Creek viewing area. The launch marked the end of the first phase of the mission for Grotzinger, nine principal investigators, and their team of about 300 scientists from around the world. That team had worked with engineers to design, build, test, and integrate the suite of 10 scientific instruments that make Curiosity a fully automated, roving geological laboratory capable of collecting and analyzing samples on the surface of Mars. Now the clock is ticking down as they prep for the next phase, when they will begin receiving images and measurements from Curiosity and using that data to seek evidence of a Martian environment

Due to Curiosity's size and mass, a new sky-crane touchdown system will lower the rover to the Martian surface. Once Curiosity touches down, the bridle will be cut and the descent stage will fly away.

that could have once supported microbial life.

That phase will begin on August 5 of this year when—if all goes well—MSL will blaze through the Martian atmosphere, traveling at a speed



of some 13,200 miles per hour. In less time than it takes to boil a pot of water—a nail-biting period known as the "six minutes of terror"—the spacecraft will go through a series of maneuvers to put on the brakes and touch down. This will be no small feat: at nearly 2,000 pounds, Curiosity weighs more than five times as much as the previously launched Mars Exploration Rovers (MERs) Spirit and Opportunity, so an air-bag bounce landing like theirs is out of the question. This time around, stages will jettison, an enormous parachute resplendent in orange and white (in Caltech's honor) will unfurl, and eight retrorockets will fire. Then, in a dramatic final act, MSL's descent stage, positioned above the rover, will behave like a sky crane, lowering Curiosity on long tethers to the surface of the planet.

Above: Curiosity's landing plan puts it within Gale Crater, an impact feature on Mars that's more than 3 billion years old. The layered mountain at its center, dubbed Mount Sharp by the science team, is a major scientific focus for the mission.

Right: These are replicas of the wheels on Sojourner (center), the first rover on Mars; the Mars Exploration Rovers (left); and Curiosity (right). Curiosity's wheels are approximately 20 inches (50 centimeters) in diameter while Sojourner's were closer to 5 inches (13 centimeters).

WELCOME TO GALE CRATER

That action-packed entrance should leave the rover poised on all six wheels inside Gale Crater, an ancient impact crater just south of the Martian equator. Roughly the size of the Los Angeles Basin—at 154 kilometers (96 miles) in diameter—the crater is the kind of place geologists would head to on Earth to search for evidence of past life. They hope to find organic compounds, the carbon-containing chemicals considered necessary for life. So finding the crater on Mars, at a safe elevation with moderate environmental conditions, made it a natural choice for the mission.

The floor of Gale Crater is at a low elevation relative to its surroundings, which means that if water once flowed across Mars, Gale might have been a location in which groundwater collected and perhaps even emerged as an ancient lake. But the main attraction at Gale is a mountain that rises five kilometers (three miles) from the crater floor. The science team has dubbed this geological feature Mount Sharp in honor of the late Robert P. Sharp (BS '34, MS '35), the beloved former chair of Caltech's then Division of Geological Sciences, who built the Institute's program in planetary sciences. Scientists hope to use Curiosity and its scientific instruments to read the history of Mars by characterizing Mount Sharp's strata—beginning with its oldest layers at the bottom and inching up to those deposited more recently. Previous orbital missions have already identified the chemical signatures of clays and sulfate minerals, which are formed through interaction with water, in the lower parts of the mountain. On Earth, these minerals are often found with—and help protect—organic compounds. All this makes the mountain a promising place to begin investigating the planet's past habitability.

"We don't know what the story is going to be at Gale Crater, but we've got a wonderfully simple exploration model," Grotzinger says, "We'll just start at the bottom of the mountain, interrogate the layers and make the measurements, and see what the planet's trying to tell us. I don't think we can lose."

Ideal though the location may be, it took the scientific community about five years to settle on Gale Crater as MSL's landing site. "The amazing thing is that, thanks to MSL's landing system, we scientists got to consider—for the first time ever—the absolute best places on Mars," says Grotzinger. "The whole time we were debating, I had seasoned veterans telling me, 'John, don't get your hopes up, because in the end engineering constraints will probably kill all of these choices. Be prepared to accept whatever's left on the table.' But we didn't have to settle. In the end, we chose the site that was actually the science team's favorite, and the engineers could support it."

SAM I AM

Curiosity is uniquely equipped to select, sample, and analyze rock and soil targets once it arrives on Mars. Indeed, JPL deputy project scientist Ashwin Vasavada (PhD '98) describes the rover as "a Mars scientist's dream machine." Its onboard tool kit includes not only devices that are the equivalent of the hand lens and drill geologists rely upon in the field, but also the spectrometers and other analytical instruments they might use in the lab to identify the chemical elements, minerals, and gases in their samples. The rover sports several cameras that will allow it to observe its surroundings in high definition and

in three dimensions. Its laser eye, called ChemCam, will zap rocks and other targets of interest from as far away as seven meters (23 feet), enabling an onboard spectrometer to get a sense of the target's composition. And Curiosity will have the ability to measure radiation, screen for water in the ground, and monitor the Martian weather.

Once Curiosity drills into a rock or scoops some soil to harvest a sample, its six-foot robotic arm will go through a series of tai-chi-like maneuvers to process and deliver the materials to the rover's belly, where they can be analyzed by two advanced onboard laboratories. One, called CheMin, will use X-ray diffraction to identify minerals in the sample. The other, called SAM (for Sample Analysis at Mars), is a suite of three analytical instruments—two spectrometers and a gas chromatograph—that can check for large organic molecules and other important chemical elements, measure isotope ratios to look for signs of past planetary changes, and determine concentrations of gases in both surface samples and the Martian atmosphere.

"Such information will be invaluable in reconstructing the geological and environmental history of Mars which, in my view, is the key to addressing the capacity of past and present Martian environments to support life as we know it," says Edward Stolper, Caltech's provost and William E. Leonhard Professor of Geology. He served as MSL's chief scientist from 2005 to 2007 and helped coordinate early development of the rover's scientific capabilities.

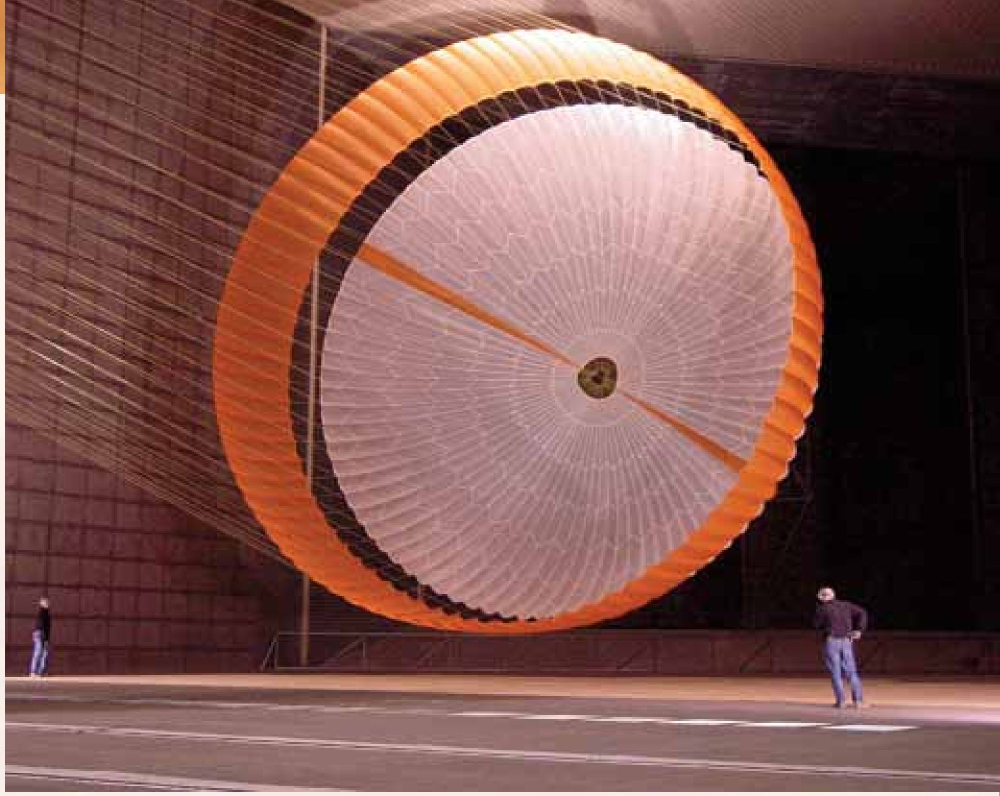
Although Curiosity is equipped to identify organics (and finding them would certainly be a grand slam for the mission) the likelihood of such a find is extremely low. That's because the surface environment at Mars is thought to be chock-full of chemicals that degrade organic matter. Compounds such as hydrogen peroxide and perchlorate, which can convert organics into carbon dioxide and other chemicals, have been detected in the Martian soil and atmosphere. Ultraviolet solar radiation and high-energy radiation from incoming cosmic rays can produce highly reactive radicals that readily alter organic matter, rendering it undetectable. Even water, which enables life to exist, tends to wipe away traces of organics because it is also an oxidant. So even if life *had* once thrived on Mars, scientists would be hard pressed to find traces of it. In fact, on Earth—a planet that teems with life—the record of life in the form of organic matter is rarely preserved over geologic time.

Not to fear, though: MSL's success does not hinge on finding organic matter. Simply by driving up the mound in Gale Crater, taking samples, and reading the layered record it encounters, Curiosity will improve our understanding of the evolution of Mars. And if it can reach a spot about a quarter of a mile (about 400 meters) up Mount Sharp, it should find a break point that may mark a geologic transition between the period when Mars was able to form hydrated materials and when the planet began to dry out. "The deterioration of Mars's early, more clement climate to the inhospitable conditions that characterize the planet today is one of the great mysteries of planetary science," says Grotzinger.

MEANWHILE, BACK ON EARTH

While Curiosity wends its way to Mars, Grotzinger and his team of scientists are doing more than just twiddling their thumbs. At JPL, rover drivers are practicing their Martian navigation using Curiosity's earthbound doppelgänger, remotely controlling the movements of the rover and its arm in either a warehouse test bed or an outdoor "Mars Yard." And the rest of the science team is working out final details related to the rover's instruments.

One working group, for instance, is compiling a list of all the different situations that could be serious uh-ohs for Curiosity's sample-handling system—such as materials that give off fluid, become sticky upon heating, or are extremely hard. "Realizing we're going to see minerals on Mars that we've never seen before, and that we



An early parachute design undergoes testing in the NASA Ames Research Center's wind tunnel. Although the final parachute design is slightly different, it retains Caltech's colors.

will have no way to really know what they are before we sample them, we have to do some hazard assessment before we would ever risk drilling into them," says Vasavada. That's why the group is testing terrestrial samples with some of these potentially problematic characteristics, and doing so in a chamber that replicates the humidity and temperature at Mars, all to see how the sample-handling system responds.

The most recent group of researchers to join MSL's science team is also busy prepping. These "participating scientists" were selected last November based on what they proposed to contribute to the mission. Caltech geologist Bethany Ehlmann wants to improve the science team's ability to respond to the data Curiosity sends back about potential rock targets. Plastic tubs in her office at Caltech are filled with basaltic rocks that have been altered in different ways through interaction with water—the same types of alteration that rocks on Mars might show if they have come into contact with water for various amounts of time. She plans to fully characterize as many of these rocks as possible, even taking them to Los Alamos National Laboratory, where she and her students can zap them with a laser similar to the ChemCam laser on Curiosity. This should help the team recognize which rock targets on Mars are worth taking a closer look at, and which to leave behind.

This isn't Ehlmann's first time at this kind of Martian rodeo. She helped operate the rovers Spirit and Opportunity—which landed on the planet within a few weeks of each other in January 2004—as an undergrad. She and the rest of the MER team even lived on "Mars time" for a few months, which essentially meant starting each workday 40 minutes later than the one before. (Martian days, or sols, last 24 hours and 40 minutes.) Curiosity's team also plans to live on Mars time for at least a few months, arriving each day just before the downlink of data from the rover's previous sol and working through the Martian night to come up with and upload fresh commands for Curiosity to execute the next Martian morning.

One of the hardest aspects of living on Mars time, Ehlmann says, is eating. "If your 12- or 13-hour shift plus your sleep time misalign with when the grocery stores or restaurants are open, you can start to wonder, 'How do I get food?'" she says. When JPL thanked the MER team for its hard work by filling coolers outside the workrooms with ice-cream treats, the running joke became, "How many ice creams have you eaten today?" Ehlmann laughs. "There were a lot of three-ice-cream days. Those couple of weeks of subsisting off ice cream were a good camaraderie-building experience for us."

That sense of camaraderie comes up time and again when people describe working on missions like MSL. Part of that closeness is based on the fact that everyone is pretty much in the same situation—waiting for new data, trying to make sense of it once it arrives, and working to make the best decisions for the rover. There's also an understanding that every member brings a different base of knowledge and experience to the team and that each skill set will be vital to the mission at different times.

Geochemist Kenneth Farley, for instance, brings a wealth of expertise in measuring noble gases in rocks. He was selected to be a participating scientist based on his proposal for determining the age of some of the geologic features Curiosity will encounter. He plans to use the rover's SAM suite of tools to measure concentrations of a helium isotope, helium-3, in heated samples. Helium-3 is the result of the extremely energetic nuclear particles that are always bombarding the surface of Mars in the form of cosmic

Below: Curiosity is the most scientifically capable rover ever sent to another planet. A rotating turret at the end of its robotic arm includes tools for studying rocks up close, as well as a brush, scoop, and drill for collecting fine samples of rocks and soils for study by the rover's analytical instruments.

rays; when they hit rocks, they shatter atomic nuclei and form isotopes such as helium-3. "If you know the rate at which these catastrophic interactions occur and you measure the isotopes that come out, then you can determine how long something has been exposed on the surface," Farley says. This could help the team select sample rocks that have been exposed for shorter periods and should thus be less altered than those that have been on the surface longer.

Since Mars geology isn't his main research area, Farley thought his proposal might be a long shot. "But," he says, "it just seemed like something that could be tried."

Back in 2001, John Grotzinger might have said something very similar. An expert in the analysis of sedimentary rock, Grotzinger has spent the majority of his career studying geology all over the world—from Northern Canada to Siberia, from Western Australia to Namibia and Zimbabwe.

But while Grotzinger was unearthing rocks in Oman, trying to better understand the composition of the biosphere 500 million years ago, a colleague suggested he submit a proposal to become a participating scientist on the MER mission. All the pictures Grotzinger had seen of Mars featured basaltic—rather than sedimentary—rock, but he decided to give it a shot. "If nothing else," he says, "I figured it would be a fun experience, and if I didn't have much to add in the end, I could go back to what I was doing."

As it turned out, shortly after Opportunity landed, the rover started relaying images of layered rock outcrops, and Grotzinger's expertise became absolutely essential; now, at the helm of the 300-plus-member science team, he'll tell you he's never really looked back.

But, if you push a little, he'll admit that maybe, just maybe, he enjoyed that evening visit to Cape Canaveral and the Atlas V rocket so much because it felt something like being back in the field. He'll admit that maybe, just maybe, he misses fieldwork. But then he'll remind you that he's even more eager to see what his team's robotic emissary will find in the Martian fields.

"Even if we don't ever find life on Mars, if we understand the evolution of its environment, we might understand why life *didn't* evolve on Mars or why it took the particular pathways it did on Earth. And that," he says, "would be remarkable. It's what science is all about." E&S

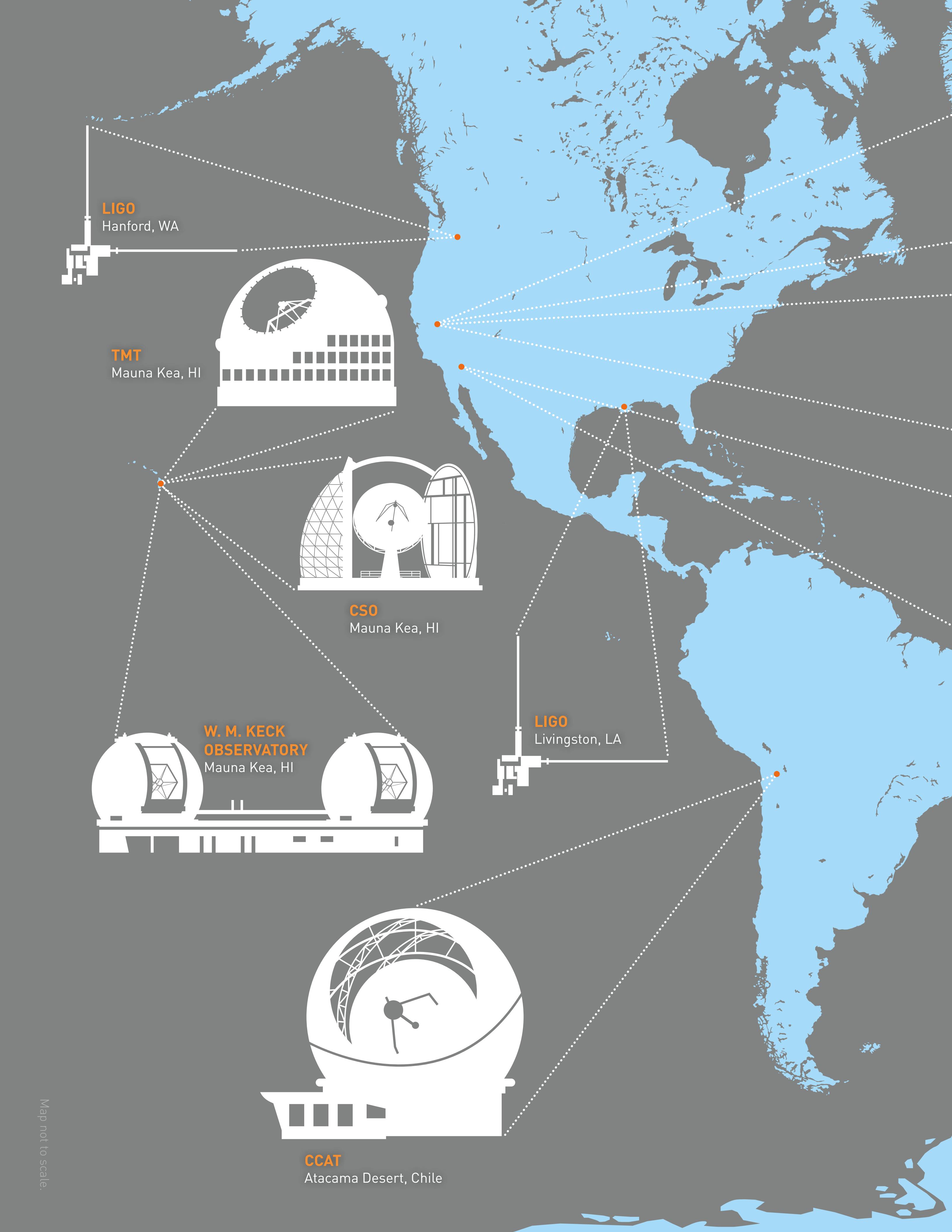
John Grotzinger, chief scientist for the Mars Science Laboratory, is the Fletcher Jones Professor of Geology at Caltech.

Ashwin Vasavada (PhD '98) is one of two deputy project scientists for MSL. He is a research scientist at JPL.

Bethany Ehlmann is an assistant professor of planetary science at Caltech and a research scientist at JPL.

Kenneth Farley is chair of the Division of Geological and Planetary Sciences and the W. M. Keck Foundation Professor of Geochemistry at Caltech.

JPL built MSL's rover and descent stage and manages the mission for NASA's Science Mission Directorate in Washington. More information about Curiosity is online at http://www.nasa.gov/msl and http://mars.jpl.nasa.gov/msl/. You can follow the mission on Facebook and Twitter at http://www.twitter.com/marscuriosity.



LIGO
Hanford, WA
TMT
Mauna Kea, HI
CSO
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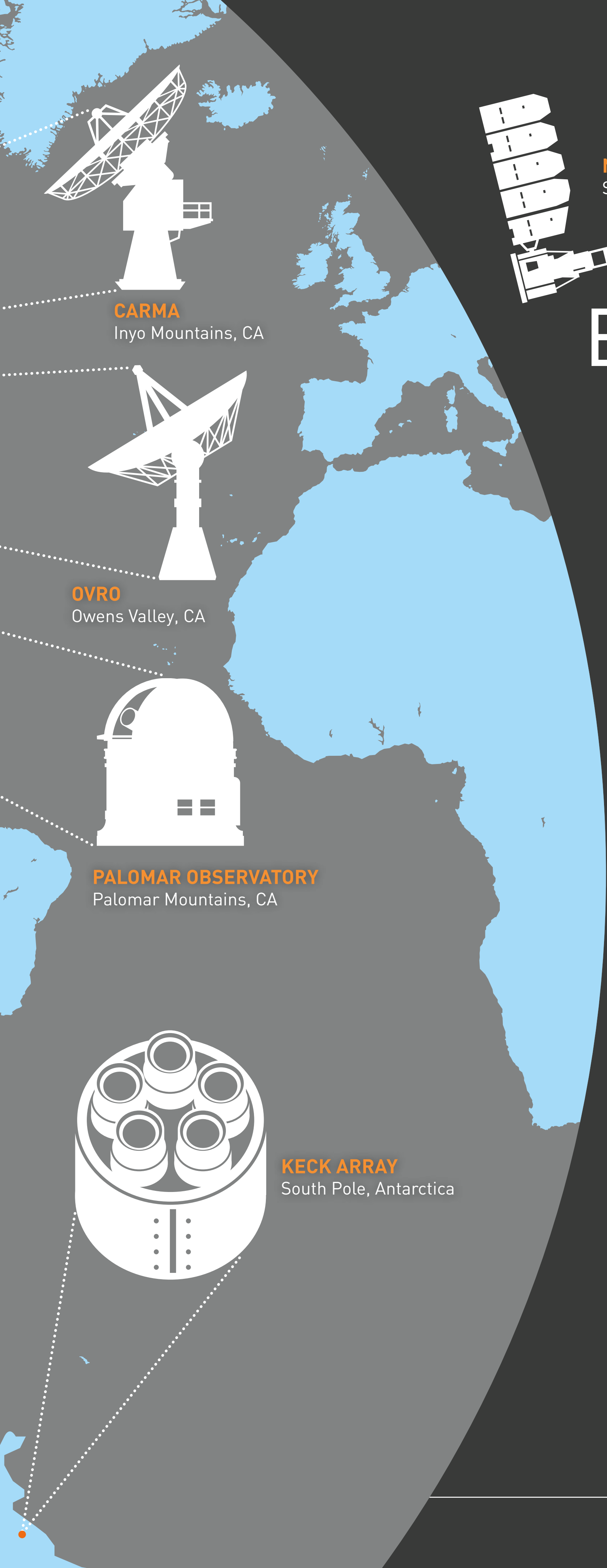
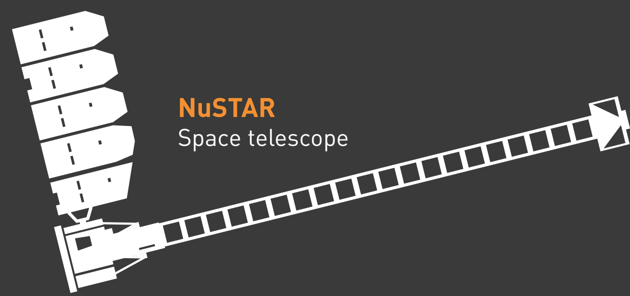
CCAT
Atacama Desert, Chile
Map not to scale.





EYES ON THE SKIES

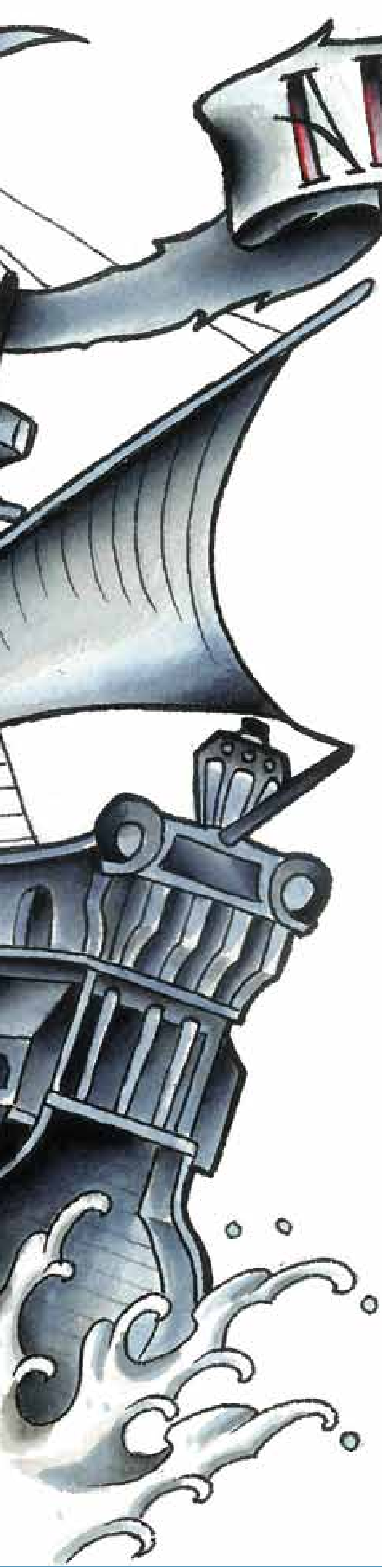
Perched on mountaintops along the western seaboard of the Americas, scattered on the heights of Hawaii, stationed in the flatlands of the United States, and positioned at the South Pole, Caltech's suite of observatories are giving astronomers, physicists, and engineers from across the globe an unparalleled view of the universe and allowing them to dig deep into the history of the cosmos. The oldest, Palomar Observatory, resides in San Diego County and has been serving the scientific space community since 1948. Further north, in the eastern High Sierras of California, the Owens Valley Radio Observatory (OVRO) is used to study cosmic radio waves and their galactic sources. Just east of OVRO is the Combined Array for Research in Millimeter-Wave Astronomy (CARMA), which consists of 23 radio telescopes working together to produce high-resolution astronomical images.

Sky surveyors also flock to Hawaii's Mauna Kea, where they have a range of instruments at their disposal, including the Caltech Submillimeter Observatory (CSO) and the W. M. Keck Observatory. The Thirty Meter Telescope (TMT) is in the works there, too, with tentative plans for it to take its place among its cousins by 2020.

In addition to TMT, Caltech has two other newcomers. Just last year, the Keck Array in Antarctica began analyzing radiation from the beginning of time, while the Cerro Chajnantor Atacama Telescope (CCAT)—still under development in the high desert of Chile—is expected to start exploring the early days of galaxy, star, and solar-system formation later this decade. And in Hanford, Washington, and Livingston, Louisiana, scientists with the Laser Interferometer Gravitational-Wave Observatory (LIGO) are taking big steps to observe these never-before-detected ripples in space-time.

While a world-class suite of land-based observatories scans the skies from below, a fleet of space telescopes is complimenting Caltech's astronomical research performed from terra firma. Scheduled for launch in June when this issue went to press, NuSTAR (above) is a NASA mission led by Caltech professor of physics and astronomy Fiona Harrison; she and her colleagues will use this latest addition to the instruments in outer space to search for black holes and map supernova explosions. —*KN* E&S

ANCHORS AWEIGH



By Katie Neith

Hydrophilic researchers take to the salty seas to gather data, explore the deep, and get a firsthand view of the beasts at the bottom. The briny treasures they collect along the way are helping them learn more about past, present, and future environmental conditions and hazards.

In the *Metamorphoses,* Ovid describes the birth of coral as the result of the blood from Medusa's severed head dripping into the Red Sea and turning all the seaweed to stone. Which is why, in 2003, Caltech's Jess Adkins, a geochemist at the Linde Center for Global Environmental Science, took an amulet of Medusa's head on a research cruise to collect samples of this calcium-carbonate-encased marine animal.

"I've always loved that story and I'll do anything for luck on a cruise, so I thought it was a great idea to take the amulet to sea with me," says Adkins. He soon learned that while Medusa does bring luck to ocean-based research efforts, sometimes that luck is *bad*. "We had horrible weather for the first week and were losing tons of research time. Finally, a crewmember pointed out that Neptune was probably really mad that Medusa was out at sea."

In an effort to turn the fate of the cruise around, Adkins devised a formal ceremony to dispose of the amulet. He gathered everyone together and read from Ovid's poem. Then he collected hair samples from the crew as an offering to the mythological sea god.

"We wrapped the hair and amulet in cloth, soaked it in gasoline, lit it on fire and shot it off the back of the ship," says Adkins, who studies coral as a means of learning more about climate change over time. "And the next morning, it was amazing. The weather was beautiful, the sea was calm—it worked! As I said, we will do anything for luck."

Maritime history is chock full of myths and superstitions. For instance, it is still tradition to break a bottle of champagne over a new boat before its maiden voyage, and, like Adkins, many people set sail with a (supposed) good-luck charm in tow. For most sailors, these rituals are meant to ensure smooth seas and bountiful sunshine on their travels. But for Adkins and the other ocean-focused researchers at the Linde Center, luck is needed not only for good weather, but also to ensure successful data collection on their sea excursions. After all, this group of scientists—which also includes geobiologist Victoria Orphan, geochemist Alex Sessions, and physical oceanographer Andrew Thompson—is looking to the deep blue for answers to past and present environmental questions that might one day shape the future of our planet.

"To do this work, we often find ourselves out at sea," explains Orphan, who averages one to four research cruises each year. "Very little is understood about deep-sea environments, even though oceans cover approximately 71 percent of our planet. Research cruises are really a great opportunity to explore new regions and learn more about this critical part of our environment."

SETTING SAIL

Caltech-led research trips—which range from two-day jaunts along a coastline to deep-sea voyages that last for months—are not just for faculty members, but also typically include both undergrad and graduate students. Since quarters are cramped, schedules are hectic, and the seas can get rough in the blink of an eye, the participants all say that a collaborative spirit between team members is essential for the success of their nautical journeys.

"You really get to bond with the people in your lab group through these experiences, which is a nice thing," says Orphan. "Advisor and student relationships take on a different energy."

Whether they're out on the high seas or bobbing about in calmer coastal regions, the scientists are looking not only for luck, but also for data. Sessions, for example, relies heavily on water collection in his work on marine biochemistry, in which he analyzes the organic particles scattered throughout the ocean.

"We want to see what's living at the surface and how it changes as it sinks down into the ocean," says Sessions, who spends less time at sea than many of his colleagues, but has managed to break away for a handful of cruises off the California coast. "We look at how the chemistry of organic matter changes as it gets older and sinks to the bottom. These are the processes that connect living stuff at the surface with what accumulates in the sediments below."

Knowing how and why organic matter gets buried on the seafloor has implications for understanding the carbon cycle—a crucial pattern of events that allows carbon to be recycled and reused by ecosystems and organisms—as well as for understanding the balance of nutrients in the ocean and how the organic-rich deposits that may someday produce oil are formed.

To measure the chemistry of the sea, Sessions and his crew use three different data-collection methods. The first involves gathering seawater in large plastic containers called Niskin bottles, which sit on a circular rack called a rosette. The rosette can hold up to 24 bottles and is equipped with a set of small sensors that measure conductivity, depth, and temperature in real time as the instrument is lowered through the water column. The bottles are open at both ends and armed with stoppers that can be triggered to trap water once the sensors indicate the bottles are submerged at the desired depth.

The second method collects organic particles by pumping water through a series of filters to capture goodies; surface water can be sampled on the boat itself, while deeper-water samples are done by sending a battery-powered pump down to desired depths and letting it run for hours at a time. These sorts of experiments take time, notes Sessions, who points out that "normal" working hours are a foreign concept on any ocean excursion. "There is a lot of setting up the experiment, sending it down, and then waiting while it filters," he says. "You really try to make the most of your time out there, even if it means sleep deprivation. The trips are always exhausting, but the fun usually makes up for it."

It's the third method of sample collection—coring sediments—that brings Sessions the most joy. There are a variety of different setups that can accomplish the task of pulling up a multilayered chunk of the seafloor, all of which can all be summed up as follows: a big tube gets jammed into the muddy bottom and sucks up numerous bands of the sediment, that, like the rings of a tree, can give the researchers insight into the ocean's ecology and chemistry at different points in history.

"When you pull the tube back up, you have this beautiful core," he says. "But that means you have a lot of work to do. After all, you can't bring a 20-foot-long core back home in your suitcase. So it all needs to be measured, sectioned, and described on the boat."

An onboard lab allows the team to make simple measurements and

preserve the sectioned samples so they can be shipped back home for analysis.

In the end, Sessions says, it's more than worth the effort. "When we do these analyses, we find that the organic material that's making it to the seafloor is chemically very different from what you find in living organisms at the surface," he explains. "So now the question is: Is it the same stuff, just chemically altered? Or was it all eaten and now we're looking at bacteria that have colonized the waste material? It turns out we don't have a great understanding of what's actually getting buried, so learning more about that process is our overarching goal."

EXPLORING THE DEEP

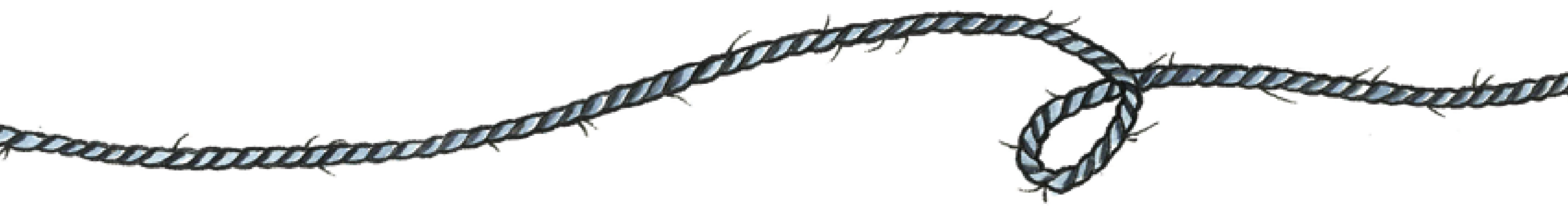
Orphan also uses water samples and coring as key methods for collecting data. But *her* overarching goal is to understand how microbial life impacts the cycling of major elements and compounds, like methane, in the environment.

"The arctic and permafrost areas are dynamic places right now, where we're seeing a lot more release of methane," says Orphan, who often travels to the Pacific Antarctic Ridge near Easter Island for her studies. This methane release is partly the result of microbial processes that break down stored carbon, she explains; and that carbon is found in previously frozen soil that has thawed, thus making the carbon available to drive the methane cycle.

"We want to understand which microbes are driving these conversions in the environment and what drives their

Previous page: Jess Adkins examines the deep-sea coral species *Enallopsammia rostrata*. Skeletons of animals like these contain chemical clues to the ocean's role in past climate change.

This page: Alex Sessions (center) helps crew members lower a rosette into the sea off the coast of California. The attached Niskin bottles collected ocean water that was later analyzed back at Caltech for its chemical composition.



efficiency and interactions," she says. "Trying to get a better handle on the microbial capacity to oxidize methane in the oceans before it reaches the atmosphere, or how to predict how much methane might be produced from stored carbon—these are important questions we're addressing."

To get cores in these cold, distant regions, a remotely operated vehicle, or ROV, is often equipped with a basket of drills and cylinders to do the dirty work. "A lot of what we are interested in is fairly close to the seafloor," says Orphan, who notes that the ROV's robot arms typically pull up pretty good samples.

Still, whenever she can, Orphan prefers to go down to the bottom for her own specimens in a Navy-owned, manned submersible called *Alvin*. At depths of nearly 4,500 meters below the surface, where near-freezing temperatures and extreme water pressure make the environment deadly to humans, she obviously can't leave the shelter of *Alvin* to core the floor or pick up her own rock samples. Still, she can get up close and personal with the objects she studies by viewing them from a window, rather than via a computer screen.

"It's so spectacular," she says. "From the moment they close *Alvin*'s hatch and start lifting you off the deck, you really feel like you're exploring in the true sense of the word. You get lowered into the water and there are these amazing changes in the light as you're submerging. Then you start to see things like bioluminescence kick in. It's about as close as you're going to get to what an astronaut might experience looking around in space."

The firsthand experience of exploring the seafloor is incredibly emotional, agrees Jess Adkins, who also employs the manned submersible in his research.

"The first time I landed on the bottom of the ocean in *Alvin*, I had to turn so no one could see me crying," he says. "When the seafloor first looms out in the lights—it's indescribable. That's probably my favorite place on Earth, down at the bottom of the ocean."

Adkins frequently dives down to the seafloor in *Alvin* to collect coral skeletons, which Adkins calls the "little tape recorders" of the sea. These ancient, fossilized animals contain trace elements and isotopes that reflect historic changes in temperature.

"I have tons of coral samples that grew for 50 to 100 years, 15,000 years ago," he says. "We can read the chemistry of, and isotopes in, their tiny calcium carbonate skeletons—which have been built up using CO_2 absorbed from the atmosphere by the sea—and interpret something about past climate change over that short window."

Because the deep ocean is the main carbon-storage reservoir on the planet, understanding how CO_2 changes with and affects climate requires knowing how that immense reservoir operates, says Adkins, who has collected corals from such places as the North Atlantic, the Southern Ocean, and the waters near Bermuda and Tasmania.

"The corals are what drive us into the deep ocean," he explains. "They can tell us something about CO_2 at different periods in history, which tells us something about climate change and the deep ocean's role in it."

UNDERWATER ROBOTS

Unlike Orphan and Adkins, who spend days on end exploring the ocean floor, Andrew Thompson sends teams of robots to do his data collection. Not because he's lazy, of course, but because he is looking to gather information over months at a time—longer than any single human could hang out on the seafloor.

The bulk of Thompson's ocean research focuses on an area in the Southern Ocean called the Weddell Sea. "The reason we're interested in this region is that it's one of the very few places in the global ocean where the water gets dense enough—due to low temperatures and high salinity—to sink all the way to the bottom," says Thompson. "And that's important for us because we're interested in how the properties of those very dense water masses, called bottom waters, are changing with time, and how that relates to climate change."

Since most of the Weddell Sea is covered with chunks of ice for most of the year, it's a tough place to get to, and a nearly impossible location to do long-term research. Which is why, on their last cruise to the area, Thompson and his team deployed new instruments called ocean gliders—autonomous underwater vehicles that will spend a couple of months traveling through the ocean, at various depths, taking measurements of its temperature and salinity, among other characteristics. The gliders are programmed to bob up to the surface every six hours, and can communicate via satellite, so Thompson can receive the data they're collecting in real time and control and adapt the mission from a laptop in his office at Caltech.

"The ability to leave them out for long periods of time is very useful," says Thompson. "I have direct communication with each glider when it's at the surface. I can get the data back, I can see where the glider is, I can talk to it. I just have to hope it keeps talking back to me."

When the devices *do* talk back, what they say should help Thompson and his team determine, for the first time, the characteristics of some of the changes that happen in the currents—like the strength of eddies, which are circular motions that lead to vigorous mixing in the seas. In particular, the team is interested in learning more about how the large amounts of iron concentrated on the continental shelf of Antarctica get moved around.

"When currents from the shelf carry iron into deeper, iron-depleted waters, it triggers large blooms of phytoplankton—organisms essential to maintaining aquatic life," says Thompson. "We would like to better understand how those eddies work to move the nutrients across an area called the shelf break, where the continent ends and slopes down in the sea. We'll get measurements of water velocity, temperature, and salinity from the ocean gliders, which will tell us a lot about the currents there."

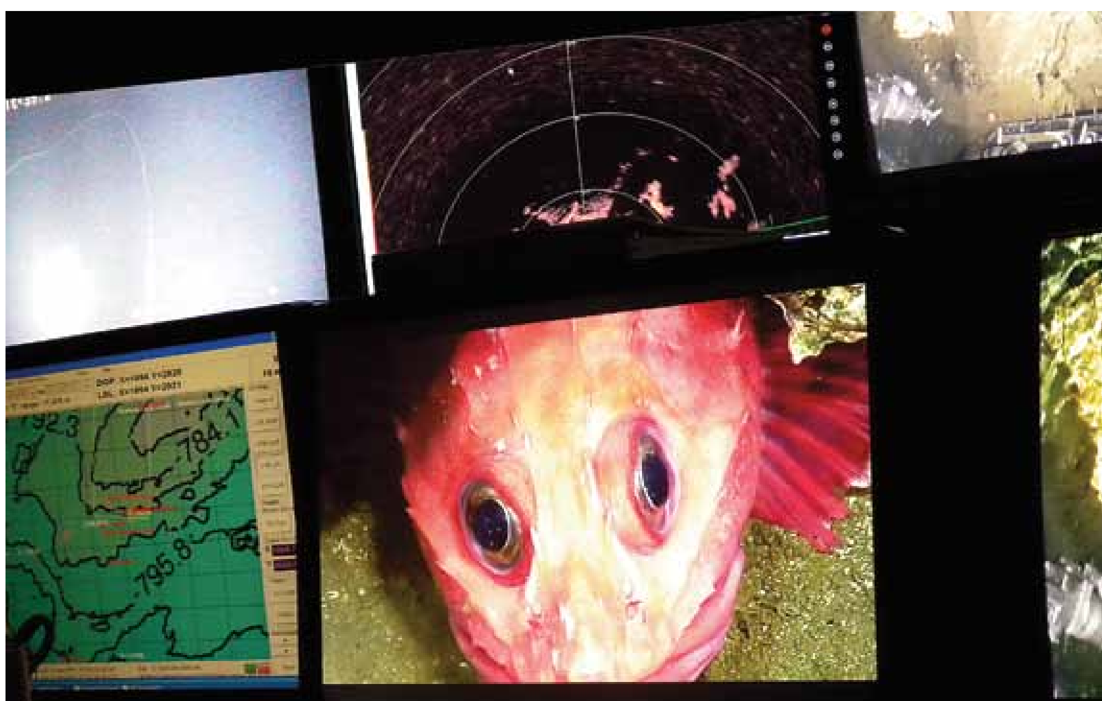
ALL ABOARD

The call of the sea may no longer be as strong as it was during the days of Magellan and Drake—when Earth's waters were essentially uncharted territory—but for the researchers at the Linde Center, there is still plenty of watery terrain left to conquer.

"Considering that the oceans cover so much of the planet, you would think we'd know a lot about them," says Sessions. "And yet, in some ways, we are at a pretty basic level of understanding things like how organic carbon gets preserved. The more difficult things are to get to and see, the less we tend to know about them."

Although resources and technology have improved to the point where it's relatively easy to collect data without leaving land, adds Thompson, there's nothing like getting on a boat and going to see the thing you're investigating—at least once in a while.

"You get a real appreciation for how vast the ocean is when you are out there," he says. "And there is still an aspect of



Previous page: Andrew Thompson, left, checks his laptop as he preps for the release of the yellow rocket-shaped ocean glider with Liz Creed, a crew member from iRobot, the company that makes the underwater vehicles.

This page: Cameras on a remotely operated vehicle broadcast scenes from the seafloor back up to a boat at the surface; those images include a bottom-dwelling fish that is clearly ready for its close-up.

exploration—going to places where very few people have been—that's very exciting."

For Orphan, these advances in technology have sparked a flood of new ideas for scientific inquiry. "With every passing year my work becomes more and more interesting because the instruments are allowing us to ask more sophisticated questions and probe deeper into hidden life," she says. "Oceanography is a field with limitless opportunities, and there is real potential to make meaningful impacts in terms of understanding environmental health."

For those willing to take on the challenge of a seafaring field of study, the thrills quickly outweigh the demands, says Adkins.

"Finding this vocation where you can both be in the lab and go out and have adventures is just a great job description," says Adkins. "You really feel like a modern-day explorer. And it's needed. We probably know more about the surface of Mars [see "Mission to Mars," page 12] than we do about the bottom of the ocean."

Even Sessions—who admits he's no sea captain at heart—says spending a few days out on the ocean provides a pleasurable break from life on land. And then, of course, there are the creatures. The scientists all have stories about whales coming up next to their ships, or sharks circling them. Thompson often sees penguins during his cruises to the Southern Ocean, and Adkins tells tales of battles he's witnessed between giant starfish and living coral.

"The coolest things that we've pulled up out of the mud are new creatures," says Orphan, who was part of a team that discovered the Yeti Crab, named for its furry shell, during a cruise to the Pacific Antarctic Ridge. "We see so much beautiful sea life when we're down in the sub, like these snails that build conical towers of eggs and sit on top of them. You'll come over a ridge and just see this city of egg-case towers, each with a little snail sitting on top. It's really spectacular. It's like a whole other planet." E&S

Jess Adkins is a professor of geochemistry and global environmental science. His geochemical oceanography research is funded by the National Science Foundation, Caltech's Davidow Discovery Funds, and the Gary Comer Foundation.

Victoria Orphan is a professor of geobiology whose work is supported by funding from the National Science Foundation, the Department of Energy, and NASA.

Alex Sessions is a professor of geobiology. His ocean-based research is sponsored by the National Science Foundation.

Andrew Thompson, an assistant professor of environmental science and engineering, is supported by the National Science Foundation and a Valentine Endowment.

FIELD NOTES

BY MARCUS WOO

Geologist Brian Wernicke painstakingly drew this field map, which depicts Death Valley's geology, over the course of many years.

When the bear started charging toward him, Jason Saleeby turned and ran. But the bear was gaining. Fast.

Saleeby, a Caltech geologist, was in Alaska collecting rock samples, toiling in a remote spot among the islands and inlets between the Pacific Ocean and British Columbia. Just moments earlier, he had used a small boat to drop off a student on a football-field-sized island, which was connected to a peninsula by a spit—a narrow ridge made out of sand. Saleeby had moored the boat where the spit met the peninsula and begun walking along the spit to join his student. Meanwhile, the student had begun hammering away at the rocks, presuming he was alone.

He wasn't. There was a black bear on the island and, startled by the sudden banging, the bear took off down the spit.

Saleeby was already halfway to the island when he saw the bear barreling down at him. The spit was long, but narrow—only a couple of meters wide. "There's only room for one of us, so I turn around and run as fast as I can," Saleeby says, recalling the scene. "He's gaining on me like crazy, and I just barely get back to the cove where the boat is."

With the bear maybe 20 meters behind him, Saleeby—with his pack and field gear strapped to his back—dove headfirst into the boat, started the motor, and backed out of the cove just as the bear arrived on the scene. The roar of the motor turned the bear around and sent it rumbling toward the peninsula and into the forest.

For a field geologist like Saleeby, close encounters of the animal kind are just part of the job. For more than a quarter of a century, Saleeby has spent a couple months each year in some of the most rugged and remote parts of Alaska, focusing on the panhandle bordering British Columbia. He and his colleagues—often the only human beings in a hundred-mile radius—spend that time recording types of rock, determining the structure and orientation of the bedrock, and sending samples back to his lab at Caltech, trying to piece together the history of the landscape. "It's a lot like being a forensic scientist at a crime scene," he says. In one case, the crime scene spanned the entire Alaskan panhandle, with the scientists piecing together evidence suggesting that the entire region had originated as a South Pacific island chain that migrated eastward for 50 million years before slamming into North America 175 million years ago.

In the pursuit of an understanding of the tectonics of mountain ranges, Saleeby has camped, hiked, mapped terrain, and chipped away at bits of rock all along the western coast of North America, from Alaska to northern Mexico. He's done fieldwork in Peru's Northern Andes and worked in the Caucasus Mountains of southern Russia. Over the last couple of years, he's been making annual trips to the Dalmatian Coast in Croatia.

Black bears are an occupational hazard when you're a field geologist. Just ask Jason Saleeby.

OUTWARD BOUND

But Saleeby is in no way unique. Caltech geologists hunting for knowledge venture to every continent on Earth—to places as distant as Antarctica, South Africa, Australia, and Sweden, and as local as Death Valley and the San Gabriel Mountains in their own backyard.

Each geologist's most elemental goal is to construct a narrative that describes how mountains rise, valleys are carved, glaciers grow, climate changes, and even how life flourishes. These findings, like those of all scientific disciplines,

depend on experiments and observations in the lab—on careful measurements of isotope ratios and rock ages, on complex computer simulations of sliding and shifting tectonic plates. But perhaps no other field requires such close and physical confrontation with nature.

"All these ideas about the history of the planet, the history of life on Earth, trace back to someone looking at a rock," says geologist Woody Fischer. "And the more rock you see, the better a geologist you are. It really is that simple. Experience is king."

Indeed, many geologists would agree that, when stripped to its essence, their field of science is about heading outdoors—sometimes to the most remote places on the planet—and engaging with Earth herself: digging, hammering, observing. To do geology is an act of intellect, but also of sweat and blood.

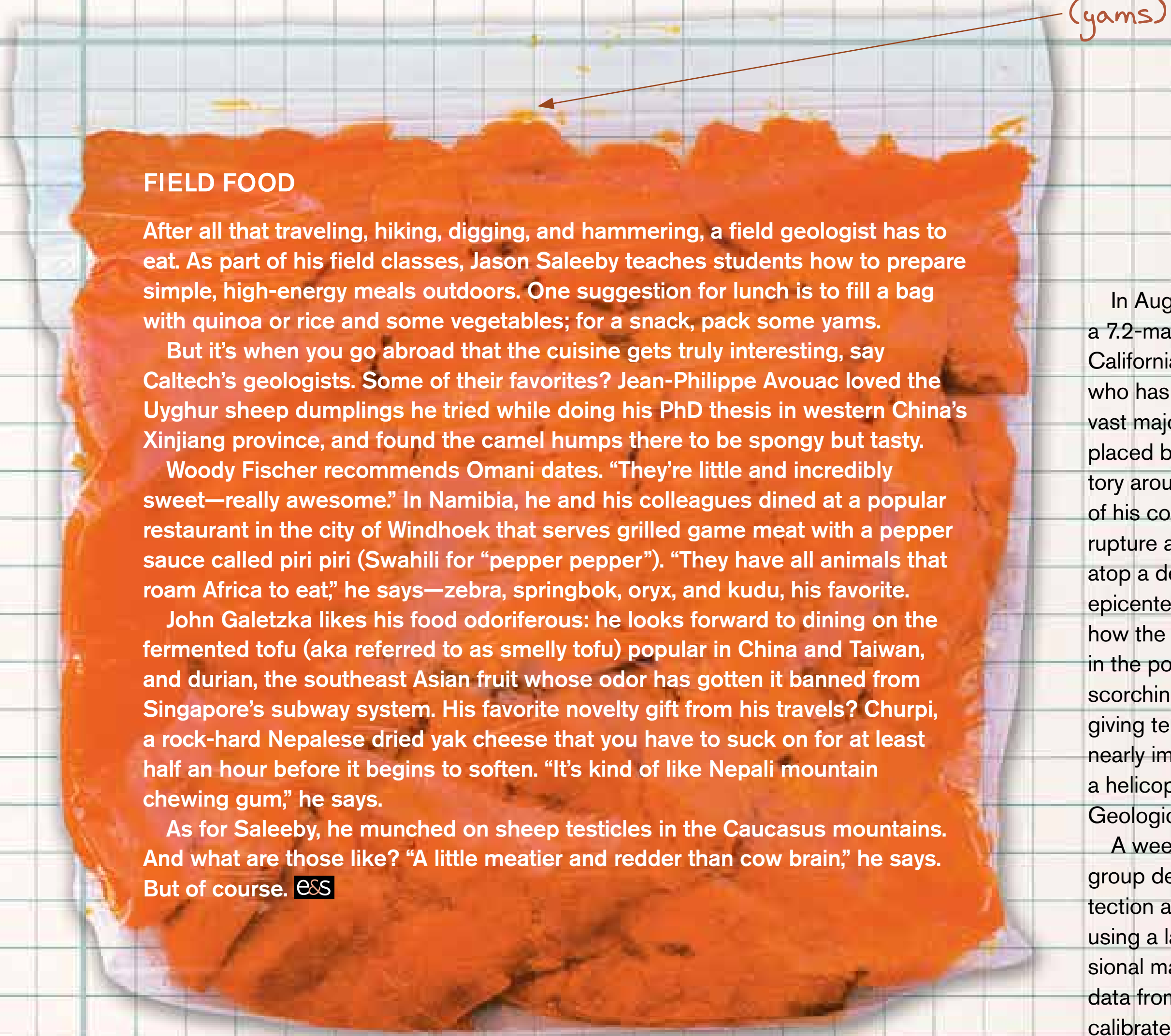
Of course, geologists often do need to bring a bit of the wild outdoors into the simpler surroundings of the lab. Geologist Mike Lamb, for instance, combines fieldwork with simulations and experiments. He built and runs Caltech's flume lab, a massive water slide for rocks and sediment that simulates what happens when rocks, mud, and other debris flow down an incline. But to fully appreciate the complexity of the landscape, Lamb says, you have no choice but to immerse yourself in it. "Sometimes," he notes, "you just have to go look the beast in the eye."

And, sometimes, that turns out to be more than just a metaphor. Geologists in the field have to worry about everything from cobras and rattlesnakes to mountain lions and elephants. In Namibia—where Fischer studies trace fossils that are important to understanding the history of life on Earth—he notes that "baboons are a major problem because they'll come down and urinate on your camp to mark their territory." In Alaska, Saleeby once found himself face-to-face with a wolverine. And then there are the bears. Saleeby's encounter in Alaska was neither the first nor is it likely to be the last in his 40-plus-year career.

Still, most of the time, it's the land itself that poses the greatest obstacle.

Top: Graduate student Kristin Bergmann hunts for fossils locked in sandstone near Menomonie, in western Wisconsin, where a sea once existed 500 million years ago.

Bottom: Geologist Woody Fischer dons a suit to protect himself from the droves of black flies and other insects that fill the air on Anticosti Island, off the coast of Quebec.



FIELD FOOD

After all that traveling, hiking, digging, and hammering, a field geologist has to eat. As part of his field classes, Jason Saleeby teaches students how to prepare simple, high-energy meals outdoors. One suggestion for lunch is to fill a bag with quinoa or rice and some vegetables; for a snack, pack some yams.

But it's when you go abroad that the cuisine gets truly interesting, say Caltech's geologists. Some of their favorites? Jean-Philippe Avouac loved the Uyghur sheep dumplings he tried while doing his PhD thesis in western China's Xinjiang province, and found the camel humps there to be spongy but tasty.

Woody Fischer recommends Omani dates. "They're little and incredibly sweet—really awesome." In Namibia, he and his colleagues dined at a popular restaurant in the city of Windhoek that serves grilled game meat with a pepper sauce called piri piri (Swahili for "pepper pepper"). "They have all animals that roam Africa to eat," he says—zebra, springbok, oryx, and kudu, his favorite.

John Galetzka likes his food odoriferous: he looks forward to dining on the fermented tofu (aka referred to as smelly tofu) popular in China and Taiwan, and durian, the southeast Asian fruit whose odor has gotten it banned from Singapore's subway system. His favorite novelty gift from his travels? Churpi, a rock-hard Nepalese dried yak cheese that you have to suck on for at least half an hour before it begins to soften. "It's kind of like Nepali mountain chewing gum," he says.

As for Saleeby, he munched on sheep testicles in the Caucasus mountains. And what are those like? "A little meatier and redder than cow brain," he says. But of course. E&S

In August 2010, four months after a 7.2-magnitude earthquake hit Baja California, geodesist John Galetzka—who has installed and maintained the vast majority of the instrument networks placed by Caltech's Tectonics Observatory around the world—went with some of his colleagues to map the surface rupture and set up a GPS station atop a desolate mountain near the epicenter. The station would measure how the tectonic plates were shifting in the postquake period. Because the scorching desert heat and rough, unforgiving terrain would have made hiking nearly impossible, they had flown up in a helicopter made available by the U.S. Geological Survey.

A week or so later, another research group decided to do a LIDAR (Light Detection and Ranging) scan of the region, using a laser to create a three-dimensional map of the terrain. They needed data from the GPS station to help them calibrate their LIDAR scan—something, it turned out, that was easier said than done, since the station's radio was broken and couldn't send data. In order for the LIDAR team to get the best data possible, someone would have to fix the radio and recover the data from its buffer right away. But on such short notice, a helicopter wasn't available.

Galetzka had been an Army Ranger at the tail end of the Cold War, training around the globe from Europe to the jungles of Panama; if anyone could brave the blistering conditions, the team decided, it would be him. "I thought about the risk: my life or the data," he says. "I'm not out there to kill myself, but I really thought that this was doable. So I said, yes, I can do it. We can do science here."

The Baja heat easily surpassed 120 degrees. Even before sunrise, when Galetzka set off alone on what would be an all-day trek, the temperature was in the 90s. There were no trails as he navigated his way up and over cliffs, sharp rocks, and boulders, lugging heavy gear and three gallons of water. He crossed paths with rattlesnakes; he worried about mountain lions and rockslide-triggering aftershocks. "It was a really, really long day," he says. "I wasn't sure if I was going to make it." But he did, and the grateful LIDAR team got their data. Combining their postquake map—which can distinguish bumps in the ground just a few inches high—with a similar but older map, the team is now able to comb the landscape for earthquake-related changes with a degree of accuracy never before possible. Some of the results of that survey were published in a recent issue of the journal *Science*.

Indeed, it helps to be an outdoor athlete—or, in Galetzka's case, to have been an Army Ranger—if you're going to work in the field. For instance, it was graduate student Jason Price's skills as a veteran climber that enabled him to scale three peaks in the Swiss Alps—including the 4,500-meter Weisshorn—last summer. He collected rock samples as he descended in order to study how their mineral composition changes with elevation.

Still, most fieldwork isn't such extreme sport. More often, it involves camping an hour or two away from a city, or even staying in a cabin or hostel, with the luxury of a hot shower at the end of a long day. And while it's important to be physically fit, you don't have to be a super outdoorsman to be a geologist. "I've seen some of the frailest people do magnificent work in the field," Saleeby says. For Fischer, the most important thing to bring to outdoor geology is good interpersonal skills. "If they can work well on a team and have a positive attitude, then that's it," he says. "We'll be successful."

Top: John Galetzka lugs a power generator weighing more than 100 pounds up a hill in La Yarada in southern Peru, near the Chilean border.

Left: MIT's Ken Ferrier, a colleague of Caltech geologist Mike Lamb, poses in an old irrigation tunnel that leads to the headwaters of Hanalei Valley on Kauai. The researchers had to hike for nearly an hour in absolute darkness to get to the rocks they wanted to sample, so as to learn how rain carves rivers and valleys.

PLANS AND PITFALLS

One of fieldwork's greatest challenges lies in its planning and logistics—in figuring out exactly which site will have the rocks you want, deciding how to transport your gear and your people, and determining how to bring back the hundreds of pounds of samples they'll invariably collect. Not to mention the complications that international travel brings. Once, in Tibet, Galetzka was almost arrested when he and his Chinese colleagues accidentally found themselves without the proper permits in a restricted area. In Iran in 2004, geologist Brian Wernicke was out in the field with colleague Jamshid Hassanzadeh and grad student Charles Verdel, studying an ancient volcano, when, with little explanation, they were escorted to the local police compound. After a couple of hours of waiting they were suddenly ordered by the police to leave the area and

WAKE-UP CALL IN NEPAL

On September 18, 2011, a magnitude-6.9 earthquake struck near the border between eastern Nepal and the Indian state of Sikkim—an area known to have extremely active tectonic plates, with the Indian subcontinent pushing into Asia and producing the uplift that keeps the Himalayan mountain range growing even today. It killed 111 people, the vast majority in Sikkim, but was felt across Nepal, sending people in Kathmandu scurrying out into the streets in the gray light of dusk. Part of the wall of the British embassy compound collapsed, killing three.

Just three days earlier, geodesist John Galetzka had arrived in Taiwan to do some maintainence work on the network of seismic monitoring instruments run by Caltech's Tectonics Observatory (TO). Once alerted to the Nepal quake, Galetzka knew he needed to act fast; this would be a rare opportunity to study the trembling tectonic plates of the Himalayan region in the immediate aftermath of such an event.

Surrounded by porters and local bystanders in the Darchula District in western Nepal, John Galetzka poses with a GPS station, one of the 27 permanent stations scattered across the country.

Two days later, he was in Kathmandu. Before heading toward the epicenter, he bought solar panels, batteries, and other gear needed to build temporary GPS stations in eastern Nepal. The temporary stations, which measure tectonic motions, would augment the TO's existing network of 27 permanent stations scattered across the country. Then, through a local friend, he hired a helicopter and pilot to take him and two colleagues, one Nepalese and one French, east.

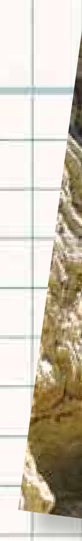
They stopped at several villages, installing the stations as fast as they could, racing against the ticking clock and the fading daylight. Although clouds and fog prevented them from landing on some of their planned sites, Galetzka managed to install enough stations to make the mission a success.

"We're in Nepal in the first place because we expect there to be a really large earthquake one day," Galetzka says. The TO's permanent GPS network measures the accumulating strain of the tectonic plates, helping to assess the possibility of such a quake—and to monitor tectonic motion before and after the Big One when it happens. "It's a very serious societal question, given the high density of population now living in northern India and Nepal," says Jean-Philippe Avouac, director of the TO.

The last large temblor in Nepal occurred in 1934—an 8.4-magnitude quake in Bihar that killed as many as 30,000 people, mostly in India. Back then, however, Nepal was sparsely populated. Today, Kathmandu is a crowded city with tall buildings, narrow alleys, streets that are barely wider than a car, and a population of almost one million. A similarly large quake in modern-day Nepal would be catastrophic.

The 2011 Sikkim quake, says Galetzka, will likely turn out to have been a much-needed wake-up call. "My colleagues in Kathmandu hadn't seen an earthquake like this in their lifetimes," Galetzka says. "They didn't react to the earthquake like we would react, in the sense of getting out to the field as quickly as possible to start collecting data from our instruments or even deploying instruments out there."

Kristel Chanard, a graduate student who spent seven months in Nepal helping Galetzka with the GPS network, had previously only experienced the country through the data in her computer. "But when I went there, I realized Kathmandu is such a huge city with really bad buildings," she says. "Then I understood that what I'm doing might help a lot of people." In other words, understanding how Nepal's tectonic plates shift, squeeze, and stretch is fascinating, but this research is about more than that. "It's not just about science," Chanard says. It's about lives. E&S



Left: Graduate student Kristel Chanard's first field trip was a three-day trek on horseback to install a GPS station in Upper Mustang, a remote region in northern Nepal.

Bottom: When John Galetzka visited Upper Mustang in 2004, unexpected weather forced him to fashion this emergency shelter out of tools and materials normally used for a GPS station.

return—immediately—to Tehran. They did as they was told.

Police run-ins aside, perhaps the biggest risks out in the field are accidents. In 2004, Wade Cooksey, a Caltech field technician who worked with Wernicke, died when he got lost in a freak snowstorm atop Mount Lewis in northern Nevada. Then there are the perils of just moving from one place to the next. Falling off a rock or getting mugged out in the middle of nowhere hardly ever happens, Wernicke says. What does happen? Auto accidents.

Wernicke would know. On July 3, 1998, he was driving south on U.S. Highway 95 near Beatty, Nevada, close to the California border. He was in the middle of installing a GPS network across the southern Great Basin as part of a study to evaluate earthquake hazards around Yucca Mountain in Nevada. The morning sun was high in the sky when a car in the opposite lane veered into his, smashing into him head-on at a combined speed of 140 miles per hour. The other driver had fallen asleep.

Luckily, everyone survived—although Wernicke suffered 13 fractures on the left side of his body and was in the intensive-care unit for two weeks. "The doctor called my injury an Evel Knievel," he says.

Wild animals. Scarce supplies. Travel fatigue. Car accidents. Considering all the potential pitfalls of fieldwork, what keeps a geologist going? Saleeby says that, at this point in his career, it's about training the next generation of geologists—not only teaching students, but helping them overcome the physical and mental demands of fieldwork. "A lot of students start out having a very difficult time," he says. "But I know that if they keep at it—and I keep at it—and if I find just the right avenue to get to them, they will all get it eventually. And seeing the lights go on—seeing in a student's eyes 'I understand what I'm doing now and I can do it'—I get really excited about that."

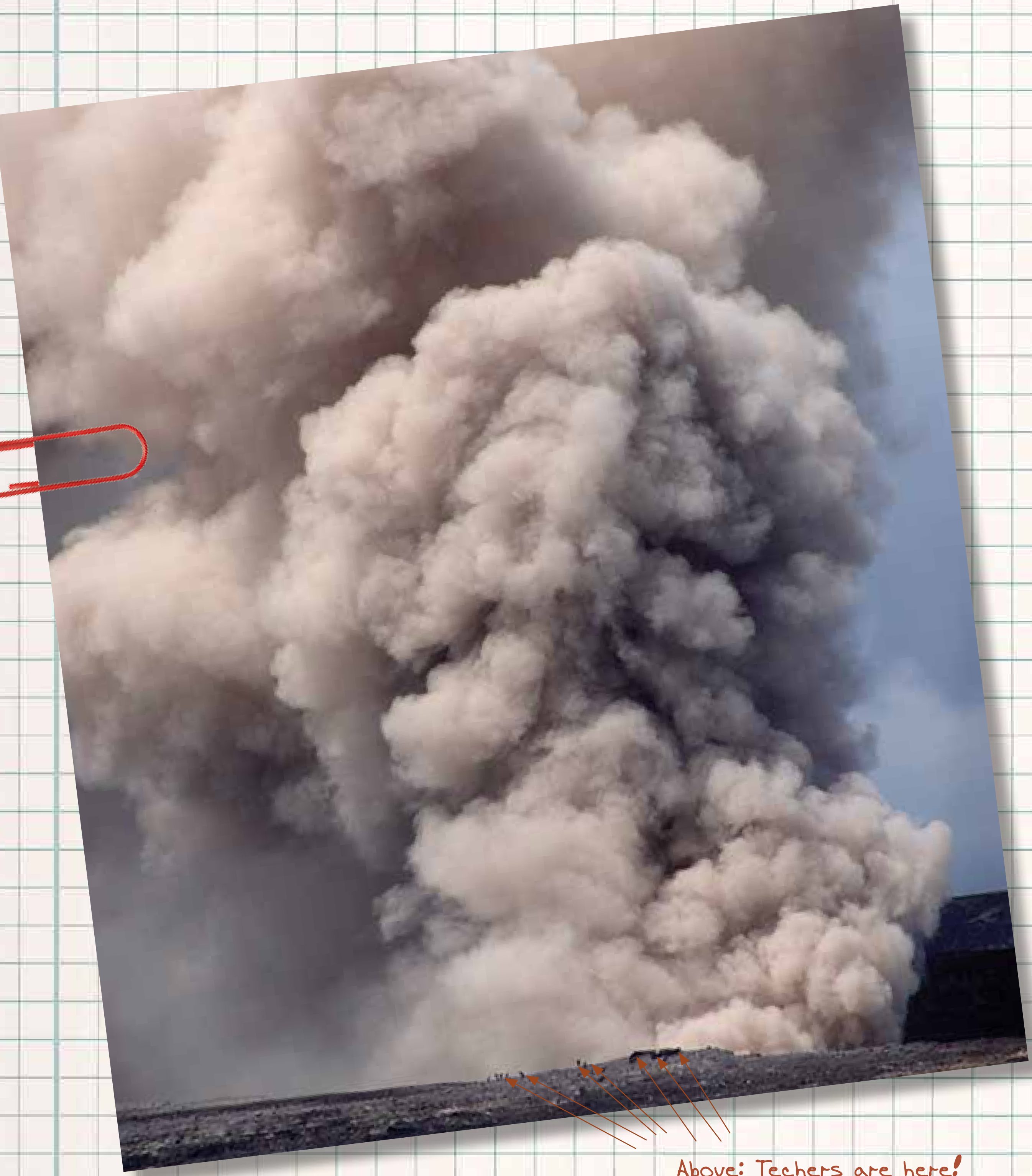
For Wernicke, it all comes down to the quest for understanding. "It's the hunt," he asserts—the desire to solve Earth's mysteries, to uncover knowledge that no one else knows. Indeed, if you ask, you'll find that almost everyone who's drawn to geology has a love for the outdoors—but, more to the point, you'll find that *all* of them have an insatiable curiosity.

"I am a complete junkie for new discoveries," Saleeby says. "That's what I live for." E&S

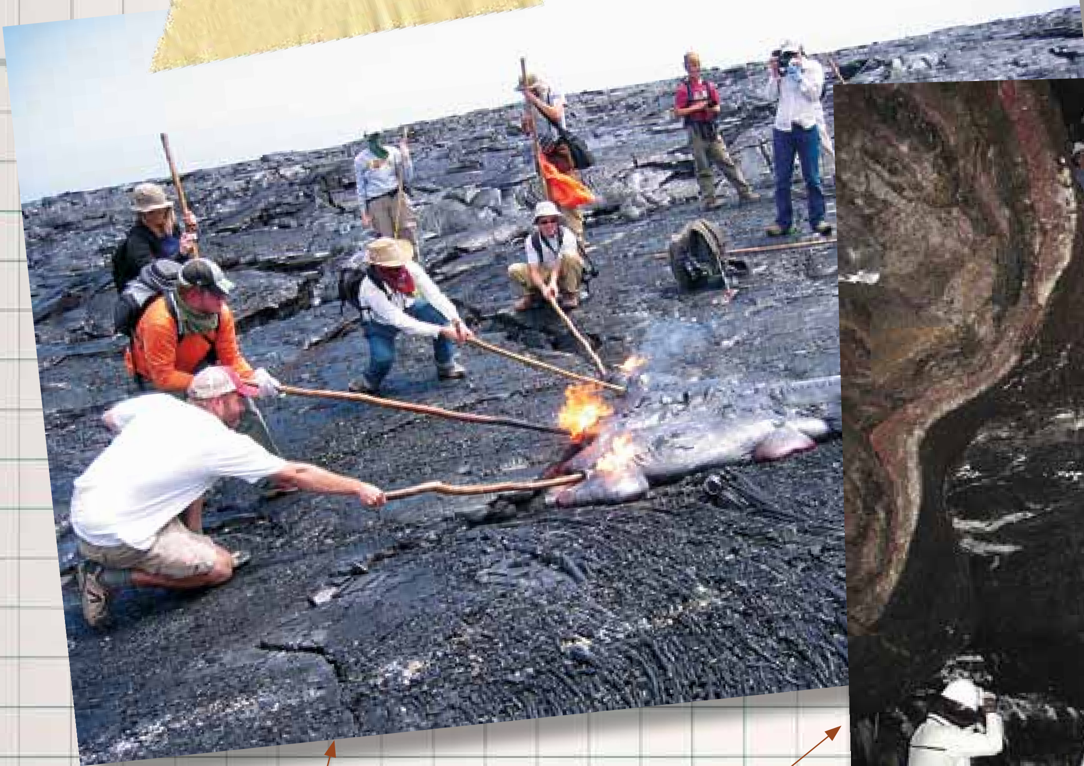
Jason Saleeby is a professor of geology whose work is funded by the National Science Foundation, the U.S. Geological Survey, and the Gordon and Betty Moore Foundation. Woody Fischer is an assistant professor of geobiology, and his work is funded by the National Science Foundation and the David and Lucile Packard Foundation. Mike Lamb is an assistant professor of geology; his work is funded by the National Science Foundation and the Foster and Coco Stanback Foundation.. Brian Wernicke is the Chandler Family Professor of Geology; his research is supported by the National Science Foundation and the Gordon and Betty Moore Foundation. Jean-Philippe Avouac is the Earle C. Anthony Professor of Geology; his work is funded by the Gordon and Betty Moore Foundation through the Tectonics Observatory. John Galetzka is an associate staff geodesist with the Tectonics Observatory.

Rocking It in Hawaii

Every March, graduating seniors and PhD students from the Division of Geological and Planetary Sciences take a faculty-led field trip to Hawaii, when they explore all the geology the island has to offer.



Above: Techers are here!

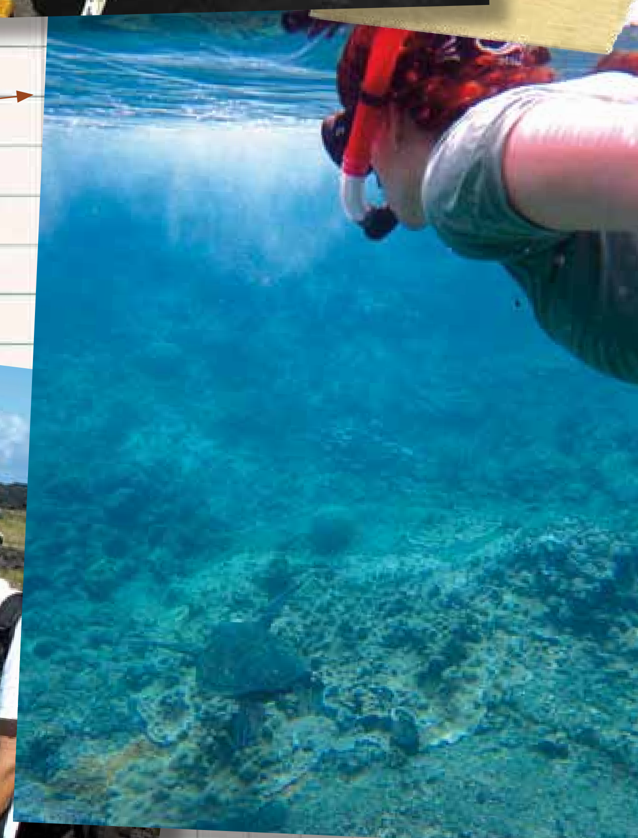


Above left: Poking at the lava.

Above right: Descending into Kazumura Cave, the longest lava tube in the world—40 miles long.

Right: Snorkeling in the coral reefs.

Below: Point taken!



ALUMNI IMPACT

Travel some surprising roads with Caltech alumni, as they make olive oil, fold paper, and start new and innovative companies.

IN THE FAST LANE

Linda Maepa

BS '96, Geology

Linda Maepa has never been one to take things slowly. A self-professed geek, she took part in science fairs in high school, doing independent research in nuclear containment and solar power.

Once at Caltech, she took a few extra years to graduate—but the rewards were worth the wait. She left Caltech with a research paper to her name; a mentor in geobiologist Joseph Kirschvink, in whose lab she had studied how proteins coevolved with Earth's early atmosphere; and a burgeoning relationship with Rob Ferber. "We were lab partners, and we got into no end of trouble in the deserts of California, having a grand old time," says Maepa.

Years later, Maepa reconnected with Ferber, one of the founders of the electric-car company Tesla. He soon became both her husband and business partner; together they started ElectronVault, which incorporated in 2007. The company invents, licenses, and manufactures technologies that enable large-scale battery systems to be produced, sold, and serviced cheaply all over the world.

"We are enabling mass-market electric vehicles that are comparable in price to conventional vehicles, and extending that to renewable energy," she says. "It has been an amazing ride."

CREATIVE CONSTRAINTS

Eric Cummings

MS '90 Aeronautics, PhD '95 Aeronautics and Chemistry

Sometimes, facing barriers can increase your creativity—at least, that's what Eric Cummings found while pursuing his doctorate at Caltech. He wanted to measure gas properties in hypervelocity flows, but the lasers in his lab were unable to make the measurements required. So Cummings developed a new technique—an experience that he says gave him "a taste for diving into foreign fields and solving highly constrained, seemingly impossible problems."

After graduating, Cummings took a job at Sandia National Laboratories in microfluidics, a field that was new to him. "I started back at square one and had to earn respectability all over again," he says.

Then, in 2005, after hearing Nate Lewis talk about global energy issues, Cummings embarked on yet another new field of research, working nights and weekends to find a scalable way to collect energy from the sun. The result: Cool Earth Solar, a company that produces solar energy through inflatable solar concentrators.

Cummings—who has just embarked on a new start-up, MaxOut Renewables—says he likes to change fields every five years or so. "I'm most innovative in a new field in the first three months," he says. "Every time you make a jump to a new area, you carry over fresh insights."

KNOW WHEN TO FOLD 'EM

Robert Lang

BS '82 Electrical Engineering,
PhD '86 Applied Physics

Robert Lang has made his mark—or, rather, his crease—on the art world. His work as an origami master has been exhibited around the world, from the Museum of Modern Art in New York to the Nippon Museum of Origami in Japan. In addition, he has taught people how to create their own origami designs, using algorithms to turn paper folds into a striking array of wonderful shapes and animals.

After studying electrical engineering and applied physics at Caltech, Lang worked at JPL for four years before moving north to Silicon Valley to work in lasers, folding the writing of six origami books into his evenings and weekends. The company he worked for was bought in 2000; the following year he decided to make origami his full-time occupation.

Lang now spends his time as an artist and origami consultant. True to his Caltech roots, he combines origami and math, applying the world of folding to real-world situations like the design of airbags and expandable space telescopes. "The most important thing I got out of my Caltech education was the idea of looking at the world in a systematic way," he says. "Most phenomena have underlying natural laws, and if you can understand what those are, then you can make progress."

GET INTO THE GROVE

Gregg Bone

BS '78, Engineering and Applied Science

Gregg Bone's passion for oil started with a question: Why does food in Italy taste so much better than Italian food in the States? "Ingredients!" exclaims Bone. "Olive oil, in particular. In an Italian kitchen, you'll find 20 to 30 bottles of different types of olive oil, each used for different dishes."

Bone, who studied engineering at Caltech, spent his early career doing special effects for Paramount, then started a number of technology companies. "If someone asked me what my job was, I'd say I'm a serial entrepreneur," Bone says. "I'm good at the beginning and the start-up stages."

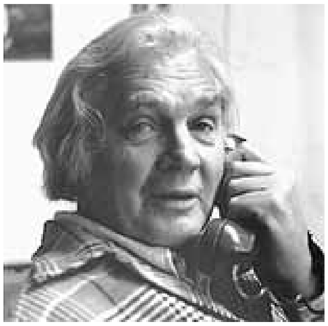
His latest start-up is Kiler Ridge Olive Farm, the result of the time he and his wife spent biking around Tuscany, where they fell in love with the food, and the time they spent in Paso Robles, where they adored the scenery. They bought 57 acres of ranch outside town and decided to plant Tuscan olive trees.

Tuscan trees need seven to eight years to fully mature, and they give their best crop of olives at around 12 years, says Bone, who started Kiler Ridge in 2005. While the farm is already producing high-end olive oil, they expect even more from it in the future.

But the farm is more about great olive oil than it is about great expectations, Bone says. "In the beginning, I put together a business plan and looked at the possibilities. Then I threw out the business plan and we went to have fun."

To learn more about these alumni, check out their extended profiles at alumni.caltech.edu/alumni_impact.

ROY J. BRITTEN
1919–2012



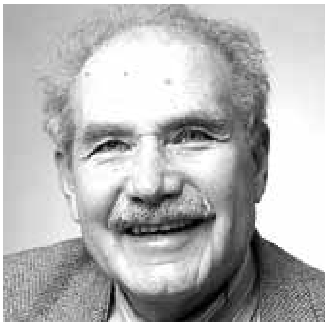
Roy J. Britten, Caltech's Distinguished Carnegie Senior Research Associate in Biology, Emeritus, passed away on January 21 at the age of 92.

"He was one of the truly brilliant people I have known," says Eric Davidson, the Norman Chandler Professor of Cell Biology. One of Britten's greatest early contributions was his discovery in 1968 that all animals' genomes—including ours—contain repeated sequences of DNA, in addition to sequences that exist only as single copies.

In 1969, Britten and Davidson published the first model of a gene regulatory network; such webs of interacting genes are now known to control animal development. In 1971, the pair published a paper concluding that the evolution of an animal's body plan depends on changes in gene regulation during development. This concept is the foundation for the field of evolutionary developmental biology.

Britten remained scientifically active until his death, publishing papers past his 90th birthday. E&S

HAROLD ZIRIN
1929–2012



Harold Zirin, professor of astrophysics, emeritus, at Caltech, passed away on January 3. He was 82.

Zirin, a solar astronomy pioneer, led the construction of Big Bear Solar Observatory (BBSO) on Big Bear Lake in California in the late 1960s. The BBSO was operated by Caltech under Zirin's direction until 1997, when it was transferred to the New Jersey Institute of Technology.

"He was a pillar of the solar community," says physicist Ken Libbrecht, Zirin's scientific collaborator for 15 years. "When people think of Hal, they think of BBSO. He conceived it, he built it, and he turned it into one of the world's preeminent solar observatories."

In the 1970s, Zirin also led the solar-astronomy research efforts at Caltech's Owens Valley Radio Observatory. Passionate about the sun, he earned the nickname Captain Corona from his colleagues and students, who depicted Captain Corona as a comic-book character—a mild-mannered professor who transformed into a caped superhero upon entering a solar observatory. E&S

BOB O'ROURKE
1939–2011

Bob O'Rourke, former vice president for public relations at Caltech, died December 27, 2011. He was 72.

O'Rourke led Caltech's then Office of Public Relations—which published *E&S*—from 1986 to 2009. Since 2009 he had been senior advisor for external affairs to Caltech president Jean-Lou Chameau.

O'Rourke was named an honorary alumnus in 1991 by the Caltech Alumni Association. E&S

WE ASKED ALUMS TO TELL US THEIR FAVORITE CALTECH SLANG. HERE'S WHAT THEY HAD TO SAY:

Snaking: studying

Hyperspace: the crawl space above South House rooms

Alley: a hallway in a House

Twitch: 1. a person lacking in the common social skills and virtues, or whose means, for one reason or another, fail to attain his or others' ends, or who is out-of-it or asocial; 2. a person who constantly makes small mistakes and faux pas; 3. the state of being a twitch *(sense 1)*

"*n* + 1 couch": any couch with *n* seats can accommodate *n* + 1 people

Gravity well: a critical mass of people talking in an **alley** *(see above)*, such that anyone else who comes by gets sucked in

Flicking: doing something that isn't the problem set you're supposed to be working on

Do-looper: *an undergrad who returns as a graduate student*

Phase-shifted: sleeping all day and staying up all night

Troll: [reputedly derived from the study halls under Bridge] *(v)* to hide from the world and work; *(n)* one who studies in excess, to the detriment of their mental and possibly physical health

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