# Where It All Began

by Robert Perkins

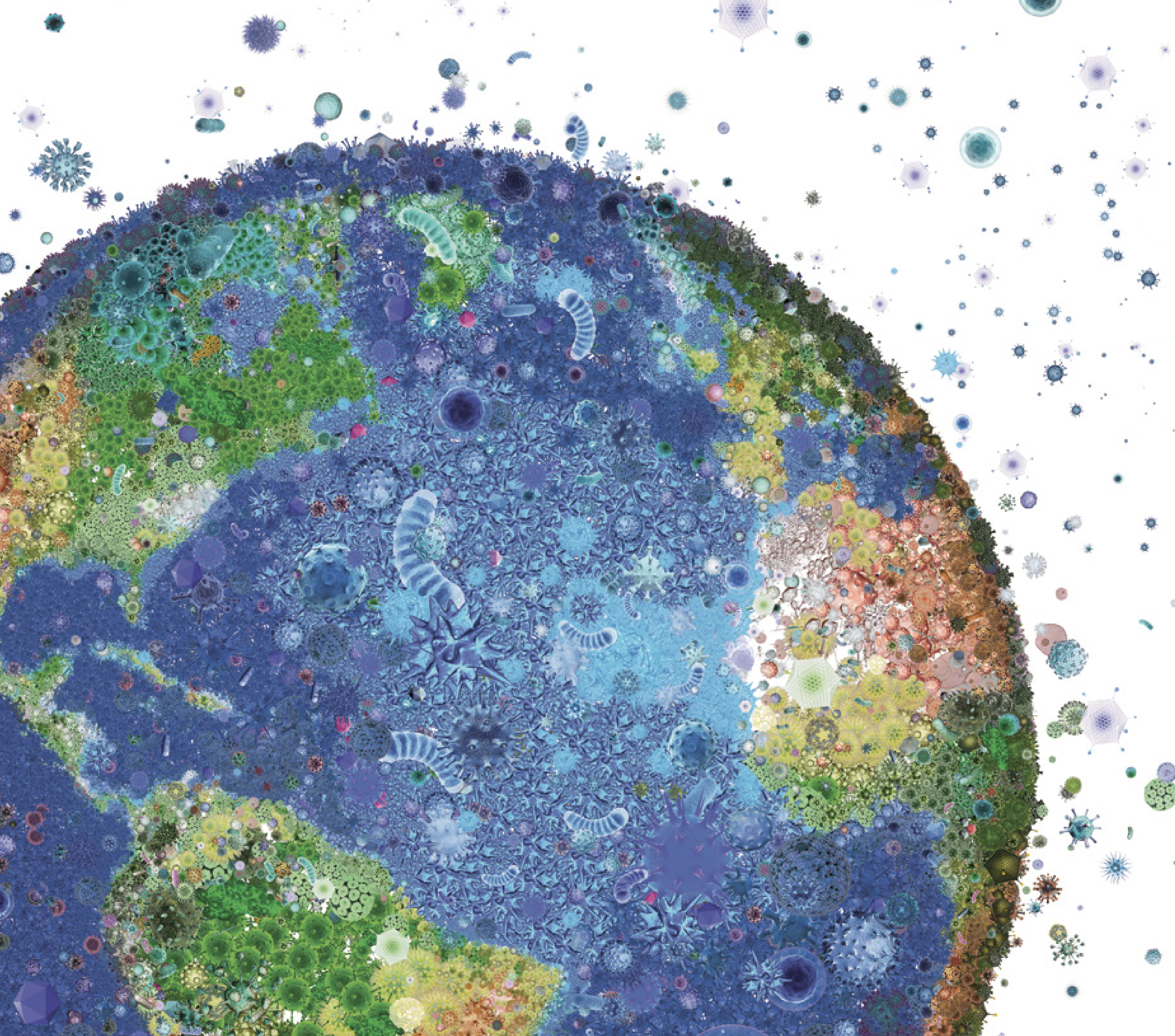

Illustration by Charis Tsevis

**Caltech's pioneering geobiology program, which began in the '90s, is uncovering knowledge about the forces that created our world and continue to shape it.**

Although Caltech's focus on the once-unheard-of field of geobiology—a combination of geology, geochemistry, and biology—may have given other universities and scientists pause, it has put the Institute in a leading position to help explain why life exists on Earth.

"Geobiology is asking very systematic questions about the coevolution of Earth and life," says John Grotzinger, the Ted and Ginger Jenkins Leadership Chair for the Division of Geological and Planetary Sciences (GPS) and the Fletcher Jones Professor of Geology. "We're merging our understanding of geologic processes in the past with modern approaches in molecular microbiology and using state-of-the-art geochemistry to explore the links between these disciplines."

Already, the research the division has done has led to insights about the origin of molecular oxygen in the atmosphere and oceans, work that shows promise in the treatment of cystic fibrosis, and the naming of two Caltech geobiologists as MacArthur Fellows.

Even with 38 tenured faculty members, the division knows it cannot do everything—and so does not attempt to do so. Instead, the division leadership has cultivated a tradition of reinvention aimed at predicting and preparing for the future. In the '50s, the GPS division sold its world-class collection of fossils to the Natural History Museum of Los Angeles County—and invested the proceeds in a new program in isotope geochemistry. At the time, the move was viewed as an odd one by the American geological community, but it paid huge dividends. Within 10 years, Caltech's geochemists were positioned to take the lead in analyzing moon rocks brought back from the Apollo missions.

It was in this spirit of reinvention that GPS put together a faculty committee in 1994 to try to peer into the future of geosciences and determine where the division should go next. The committee was led by Peter Goldreich, now the Lee A. DuBridge Professor of Astrophysics and Planetary Physics, Emeritus. In what came to be known as the Goldreich Report, the faculty specifically identified geobiology as a field to build on for the future.

Joseph Kirschvink, at the time Caltech's only geobiology professor, recognized the potential to think of DNA not as a finished product but as an evolutionary record. And though the gene-sequencing revolution that made DNA analysis cheap and easy was still a decade away, Kirschvink quickly became the leading voice in the push toward geobiology.

"My colleagues [at other institutions] scratched their heads and said, 'What are you doing?'" says Kirschvink, the Nico and Marilyn Van Wingen Professor of Geobiology. "But a few years later, they were scrambling to catch up."

William E. Leonhard Professor of Geology Edward Stolper, who was division chair at the time, took the Goldreich Report and committed the division to hiring several new faculty members in the broad area of geobiology—but without increasing the size of the department. Starting with Dianne Newman in 2000, Caltech has hired five faculty members who are now part of the geobiology program. In that time, the GPS division also established geobiology options for both undergraduates and graduate students.

## Right time, right place

When Stolper committed the division to building a geobiology program at Caltech, the allocation of such substantial resources was not without risk. As a field of scientific inquiry, geobiology had existed for over a century—at least since the late 1800s, when Russian microbiologist Sergei Winogradsky first began looking at how organisms metabolize minerals. But for years, it was something of an academic fringe area.

Shortly after Caltech began investing in the field, however, technological advances—including the new genome-sequencing methods—gave it a jump start. Completed in 2000, the first human-genome sequencing cost about $2.7 billion and took 15 years. Today, that same analysis costs just over $1,000 and can be completed in a matter of days—and for microorganisms, the cost is far lower, and the analysis can be completed in a matter of hours.

In broad terms, geobiology gives scientists a framework for asking questions about

From left: Edward Stolper, Mel Simon, and John Abelson on a field trip in Western Australia to look for evidence of the earliest history of life on Earth.

how life on Earth evolves, as well as how its evolution influences and is influenced by its environment. For example, one of the first big geobiology questions tackled by Caltech researchers focused on the origin of oxygen in Earth's atmosphere. The geological record indicates that sometime around 2.5 billion years ago, oxygen abruptly became prevalent in the atmosphere. This event, known as the Great Oxygenation Event, fundamentally changed the planet, making complex, multicellular life possible. Geobiologists at Caltech connected this event to the evolution of photosynthetic cyanobacteria.

"Only because of life do we have significant molecular oxygen, which influences the evolution of the planet. But also, life evolves and develops in a geological environment," Stolper says. Most of the genetic sequence encoded in our DNA evolved billions of years ago when Earth was a very different place, and the sequence itself and the biological processes it encodes can tell us something about what that place was like, he says.

In 2016, geobiology professor Woody Fischer proposed that the planet-shaping evolution of oxygenic photosynthesis came about just once, around 2.5 billion years ago. No other organism duplicated the process—instead, plants, algae, and other organisms that perform oxygenic photosynthesis simply "borrowed" the technique by subsuming cyanobacteria as organelles (chloroplasts) in their cells at some point during their evolution, according to endosymbiotic theory.

Geobiology's insights are not limited to the ancient past. Molecular biologist Dianne Newman, the Gordon M. Binder/Amgen Professor of Biology and Geobiology, focuses her work on microbial stress responses, with an emphasis on how microbes generate energy and survive when oxygen is scarce. Last year, she and her colleagues used soil samples collected in the courtyard of Caltech's Beckman Institute, isolating a bacterium that produces a small protein called pyocyanin demethylase (PodA), which inhibits the development of biofilms of *Pseudomonas aeruginosa*, a major opportunistic pathogen found in a variety of infections.

Grotzinger, who was recruited into the geobiology program from MIT in 2005, has applied the principles of geobiology to his work as project scientist for the NASA/JPL Mars Science Laboratory Curiosity rover, searching for evidence of ancient environments that could have been habitable for microbes. By understanding how geobiology is applied to the study of early environments on Earth, the Curiosity science team was able to constrain the salinity, redox state, and duration of ancient martian water bodies, and whether they contained dissolved nutrients and even organic compounds.

Beyond gene sequencing, several techniques and technologies that are fundamental to geobiology also blossomed during the early 2000s, including the ability to take in-situ samples of microbes and analyze their genomes without having to culture them in a lab, and to use stable-isotope labeling to reveal the composition of cells. Victoria Orphan, the James Irvine Professor of Environmental Science and Geobiology, has used these techniques to study microorganisms that live in deep-ocean sediment beds and consume large quantities of methane released from seeps in the ocean floor. She and her colleagues have also studied soil samples from the 2015 methane leak at Southern California Edison's Aliso Canyon storage facility to learn more about the methanotrophs—microbes that consume methane—that could one day be used to mitigate such disasters.

Research in the geobiology program has not only helped to attract outstanding students, postdoctoral scholars, and faculty members to this new field, but the work has also led to recognition from the scientific community as a whole, including the naming of Newman and Orphan as MacArthur Fellows last fall.

## A little help from our friends

It is impossible to tell the story of geobiology without recognizing the instrumental contributions of the Agouron Institute, says Grotzinger.

A nonprofit organization formed in 1978, the Agouron Institute owned part of a successful company, Agouron Pharmaceuticals, which saw great success through the creation of a widely used HIV protease inhibitor, Viracept. The Agouron Institute has used that success to help fund research primarily in biology and geobiology. The institute has strong ties to Caltech: its president and executive director is John Abelson, Caltech's George W. Beadle Professor of Biology, Emeritus; and its chairman of the board of directors is Melvin Simon, the Anne P. and Benjamin F. Biaggini Professor of Biological Sciences, Emeritus. Grotzinger and Stolper also sit on the board of directors.

Abelson and Simon took an early interest in geobiology, starting with an assessment of the field in 2001—led by Newman. One of the Agouron Institute's most visible contributions to the field of geobiology has been the support of fieldwork, including the establishment of the International Geobiology Course, now run by Caltech, which brings together students and faculty from biology, geology, and chemistry, allowing them to learn from one another beginning with all-important course work in the field.

"It's become a legendary class," says Newman, "and many of the people now in prominent faculty positions throughout the U.S. went through that course at one point." The Agouron Institute followed up on its support of the geobiology course with a postdoctoral fellowship program that it continues to support.

## From the deep past to the stars

Looking to the future, Grotzinger expects geobiology to become increasingly important in the study of exoplanets. He and Fischer are currently studying Mars as an analog for an Earth-like planet that might have once had oxygen in its atmosphere as a result of inorganic processes.

In a competitive world, Stolper sees the geobiology program as another way that Caltech is distinctive. "This focus gives you an advantage—graduate students will come, postdocs will come, people on sabbatical will want to come, people who want to become faculty members in that area will come."

Geobiology is the latest success story, he says, but it's simply an example of a mind-set the Institute has always had. "These programs always started with hiring somebody about whom everybody thinks, 'This person's never going to fit in because they're a chemist, they're a physicist, they're not going to be comfortable here.' And then they just take off. In the end, those people are the pioneers." [C]

For an expanded version of this article, go to magazine.caltech.edu/post/where-all-began

Clockwise from left: Kyle Costa, a postdoctoral scholar, collecting soil in the courtyard of Beckman Institute from which Dianne Newman's lab isolated a bacterium that disrupts biofilms. Research scientist Patricia Tavormina removes a small amount of Aliso Canyon soil from frozen samples for DNA extraction as part of a collaboration with Victoria Orphan. GPS graduate student Nathan Stein (at right) conducting summer research fieldwork on Turks and Caicos's Little Ambergris Cay, along with Maya Gomes from Johns Hopkins. *Oxphotobacteria* in microbial mats in Yellowstone.