Next, his lab scaled up the project with a nearly 300-person population survey to see whether or not calcium isotope levels vary demographically or over short periods of time in healthy people. As a result of their findings, the Tissot lab has developed procedures for handling more than 100 samples in a single week, indicating that their techniques could one day be scaled up and implemented in clinical settings that manage larger volumes. "We can now do measurements that are unparalleled in precision and at such a rate that large-scale clinical studies are possible. We're starting to design them now," Tissot says.

In addition to the osteoporosis project, Tissot remains connected to his planetary science roots. Recently, Tissot gave a lecture discussing how samples returned from Venus could tell us at what point in their evolution Earth and its twin diverged so dramatically. "Whether it's in the human body or outer space, isotopes respond to the same general rules no matter the system," he says. "If the question is interesting, the isotopes allow you to study it."

Learn more about how sample return work continues to play an important role in Caltech's Division of Geological and Planetary Sciences.

Eiler's Machine

In 2003, Eiler began working with LA-based Thermo Fisher Scientific to achieve his goal of nailing down the exact locations of isotopes within atoms in order to unlock vast amounts of molecular information. The trick was convincing the manufacturer that new types of machines designed for this purpose would not only function, but that they would be used by other researchers. "I think they thought I was crazy," Eiler recalls.

Although the first generation of this new mass spectrometer was capable of studying only a small fraction of the chemical compounds he hoped was ultimately possible, Eiler produced some preliminary findings and began to give talks around the world about the machine's potential for breakthroughs. As knowledge of the instrument and its use grew, and with as many as 50 other labs signaling their interest in the technology, Thermo Fisher became convinced of the utility in developing the product, which would eventually become known as the Orbitrap mass spectrometer.

Eiler filed a patent and continued to work through generations of increasingly more capable designs of the Orbitrap with Thermo Fisher engineers, visiting the company's factory in Germany multiple times. The Orbitrap's capabilities expanded, enabling researchers to examine the isotopes in more complex molecules. And Eiler continued to demonstrate its value through his own research. In 2011, his team showed that isotopes in fossilized dinosaur eggshells could be used to directly measure, for the first time, the body temperatures of ancient dinosaurs. In the years since, Eiler's lab has made similar breakthroughs in the understanding of the ancient climate on Mars and the origins and fates of methane and other organic molecules in the natural environment.

In the last decade, Eiler's dream of creating an atom-by-atom view of a wide range of molecules has been realized. Thanks to the Orbitrap, more precise measurements of isotope ratios have been made possible—even in small samples. This ability could prove crucial in planning future missions to study samples returned from other bodies in the solar system like asteroids and Mars.

Orbitrap mass spectrometers are now up and running in labs around the world, and multiple versions of the machine are now available. They are making a difference on campus as well. In addition to the work Tejada and Tissot are doing, collaborators across Caltech are using the Orbitrap in a wide variety of studies: to look at the degradation of plant litter in soil, the "prebiotic" chemistry that enabled the emergence of life, and more. Eiler's team even uses it to help detect steroidal doping in elite athletes, funded by the research collaborative Partnership for Clean Competition. "Molecules of synthetic testosterone look identical in shape to the testosterone naturally produced by your body, but not when you really scrutinize down to the isotopic level," Eiler explains. "We can take blood samples and see if the testosterone all looks the same, or if there are two different kinds—which would indicate that someone was doping."

The Orbitrap's diverse applications are the reason Eiler dedicated so much time to building the technology. "You don't ask the first person to invent a telescope what star they're looking for," Eiler says. "This is to look at absolutely everything. If there's a molecule, and you have a question about it, we can do something to answer it."

Eiler's successful journey to expand the realms of possibility builds on a legacy of geochemistry excellence at Caltech that helped draw both Tejada and Tissot to Pasadena. "John is the man," Tissot says. "It's inspiring to be surrounded by people who are legends in their fields." C

John Eiler is the Robert P. Sharp Professor of Geology and Geochemistry and the Ted and Ginger Jenkins Leadership Chair of the Division of Geological and Planetary Sciences. His work is funded by the National Science Foundation, among others.

Julia Tejada is an assistant professor of geobiology and a William H. Hurt Scholar. Her work is funded by the Shurl and Kay Curci Foundation, among others.

François Tissot is a professor of geochemistry and a Heritage Medical Research Institute Investigator. His work is funded by the Heritage Medical Research Institute, a Packard Fellowship, and the National Science Foundation.

An Intriguing Red Planet Rock

A sample discovered by the Perseverance rover offers hints that Mars may have hosted microbial life billions of years ago.

By DC Agle

NASA's Perseverance Mars rover used its Mastcam-Z instrument to capture this view of the Cheyava Falls rock sample within the rover's drill bit.

A vein-filled rock nicknamed "Cheyava Falls" discovered by the Mars Perseverance rover on the northern edge of Jezero Crater in July 2024 contains fascinating traits that may indicate possible signs of ancient microbial life.

The rock, which measures 3.2 feet by 2 feet, exhibits chemical signatures and structures that could have been formed by life billions of years ago when the area being explored by the rover contained running water. The rock was collected on July 21, 2024, as the rover explored an ancient river valley called Neretva Vallis that measures a quarter-mile wide and was carved by water rushing into Jezero Crater long ago. Multiple scans of Cheyava Falls by the rover reveal it contains organic compounds. While such carbon-based molecules are considered the building blocks of life, they also can be formed by nonbiological processes.

"Cheyava Falls is the most puzzling, complex, and potentially important rock yet investigated by Perseverance," says Ken Farley, Caltech's W. M. Keck Foundation Professor of Geochemistry and Perseverance project scientist at JPL, which Caltech manages for NASA. JPL manages the Mars 2020 mission. "On the one hand, we have our first compelling detection of organic material, distinctive colorful spots indicative of chemical reactions that microbial life could use as an energy source, and clear evidence that water—necessary for life—once passed through the rock. On the other hand, we have been unable to determine exactly how the rock formed and to what extent nearby rocks may have heated Cheyava Falls and contributed to these features."

> "To fully understand what happened … we'd want to bring the Cheyava Falls sample back to Earth, so it can be studied with the powerful instruments available in laboratories."

Running the rock's length are large white calcium sulfate veins, between which lie bands of material whose reddish color suggests the presence of hematite, one of the minerals that gives Mars its distinctive rusty hue. When Perseverance took a closer look at these red regions, it found dozens of irregularly shaped, millimeter-sized off-white splotches, each ringed with black material akin to leopard spots that contain both iron and phosphate.

"These spots are a big surprise," says David Flannery, an astrobiologist and member of the Perseverance science team from the Queensland University of Technology in Australia. "On Earth, these types of features in rocks are often associated with the fossilized record of microbes living in the subsurface."

Spotting of this type on sedimentary terrestrial rocks can occur when chemical reactions involving hematite turn the rock from red to white. These reactions, which may serve as an energy source for microbes, can also release iron and phosphate, which cause black halos to form. In one scenario posed by the Perseverance science team, Cheyava Falls was initially deposited as mud with organic compounds mixed in that eventually cemented into rock. Later, a second episode of fluid flow penetrated fissures in the rock, enabling mineral deposits that created the large white calcium sulfate veins seen today and resulting in the spots.

"To fully understand what happened … we'd want to bring the Cheyava Falls sample back to Earth, so it can be studied with the powerful instruments available in laboratories," Farley says. C