Profile of Susan Brantley

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As a bus rattled down the Pan American Highway across the sun-washed desert of northern Peru in 1980, a young American woman gazed out the window at buttes and bluffs, searching for a flagpole that would point the way to the result of a rare phenomenon on Earth’s surface: a massive salt deposit, formed when water from the ocean gradually evaporated over a 20-kilometer stretch. Around midnight, the bus dropped off Susan L. Brantley, who was on a Fulbright scholarship in Peru. The next morning, Brantley gathered her pack and walked west into the desert, hiking up a butte to locate a research camp near the salt deposit.

Although Brantley had come to Peru to study an unrelated topic—the impacts of heavy metal mining on rivers in the central valley—samples from the rare deposit led to her first major scientific publication (1) and foretold her current reputation as a prominent figure in geochemistry at Earth’s surface.

Now a Distinguished Professor of Geosciences and Director of the Earth and Environmental Sciences Institute at Pennsylvania State University, Brantley has developed innovative strategies for measuring how natural processes, such as weathering, unfold in the environment. “We’re changing the planet so quickly now,” Brantley says. “I want to understand how our human impact is going to change our environment.”

Much of Brantley’s childhood was spent in a suburban jungle of backyard swing sets, neighborhood races, and mud pies in Rochester, New York. “My mom was always telling us that we had to go outside. There were no fences, so we’d all run in packs up and down the neighborhood.” Her impressive high school transcripts made it difficult to narrow down college admission offers. Brantley enrolled at Princeton University, eventually focusing on a field she considers central to the fabric of life: chemistry. “I think of physics as a loom with the warp of threads going down. Then the threads that are woven in across as the weft, all different colors and textures, that’s what I think of as chemistry. All the different types of elements built into the structure of that loom.”

Brantley soon realized that chemistry is a field with many diverse threads. After a brief stint in the research laboratory of famed theoretical chemist Lee Allen, she moved to a laboratory overseen by one of her geochemistry professors.

Chemistry of Rocks and Water

In a fortuitous twist of fate, Brantley entered the field of geochemistry when she enrolled in a course taught by geologist David Crerar. “It was all about the chemistry of water and rock, and why water looks the way it does,” she recalls. “What controls it? And how do soils form? I loved it.”

Brantley’s interest in geochemistry intensified in 1980 when she won a Fulbright scholarship to study mining in the high Andes of central Peru at the Cerro de Pasco mine. After her year in Peru, she returned to Princeton for graduate school, earning a doctorate in geosciences under the mentorship of Crerar and comentor Brian Evans. One of her first publications based on her dissertation work was an investigation of the Peruvian salt evaporite (1).

When Brantley published her observations in 1984, researchers were struggling to calculate the concentration and activities of dissolved salts in water. “When seawater evaporates and becomes saltier, it’s hard to calculate when salts should precipitate. We’re really...
good at making calculations in dilute solutions, but when it gets concentrated, like halite-precipitating solutions, it’s difficult.”

Brantley’s graduate research was guided by a number of informal mentors in the geosciences department, including professors Robert Hargraves and Lincoln Hollister, as well as Maria Borcsik, a longtime manager of Crerar’s laboratory.

In 1986, months before defending her doctoral dissertation, Brantley’s advisor encouraged her to apply to a tenure-track position as assistant professor in the geosciences department at Pennsylvania State University. “This is the only faculty job I’ve ever applied for. They offered it to me, I took it, and I’ve been here ever since.”

Navigating those first months as a professor—and last months as a graduate student—was tricky. “I used to drive to Penn State, where I was the only female faculty member in my department, back to Princeton to be a graduate student again. I used to tell people the state line determined whether I was a grad student or faculty.”

During her first year on the Pennsylvania State University faculty, Brantley published a paper in Nature describing her analysis of water from a crater lake at the top of an active volcano in Costa Rica. “That lake had been described to me by a volcanologist from Dartmouth as being a very salty acid lake. It turned out that its water was more acid than almost any other place on the planet.” Volcanic gases are acidic, Brantley explains. In most other environments a crater lake’s acidic water would be neutralized by rocky lakebeds, which introduce alkalinity as they dissolve. “But here, we found that the acid was coming up faster than the rocks could dissolve into it. The volcanic gas would come up and condense in the lake, and it would just drive the lake more and more acid,” she adds.

The analysis inspired similar projects at Yellowstone National Park, where Brantley and then-graduate student Cindy Werner measured CO₂ fluxes as a means to estimate the rate of release of gas from subsurface magma. In that project, the pair collaborated with a meteorologist to examine how a technique called Eddy Correlation Analysis, used by meteorologists to measure the flux of gas, could be applied to volcanic degassing to extrapolate the gas flux over the Yellowstone park.

Earth’s Weathering Machine
During her seventh year at Pennsylvania State University, Brantley took an 8-month sabbatical at the US Geological Survey, studying rock weathering and soil formation alongside geologist Arthur White. The pair hit upon a central puzzle that has since occupied most of Brantley’s career: How can researchers measure geochemical reaction rates in the laboratory and extrapolate those findings to the field? Studying water-mineral interactions and water-mineral dissolution reactions in the laboratory seems practicable, Brantley says. But extrapolating the findings to an observable phenomenon in the geologic record was nearly impossible.

In a recent paper, Brantley and French geoscientist Yves Goddéris used Goddéris’ model to predict how quickly weathering reactions would happen in the next 100 years. “With climate change and changing CO₂, the rate that soil dissolves into water is going to change. So we were studying the record of change in the past and making calculations into the future. That’s exactly the kind of thing that geologists are always trying to do.”

Brantley and White coined the phrase “the Earth’s weathering engine” to describe the dynamic process of soil creation. Geologists commonly think about weathering and erosion from the perspective that rocks are heated at depth. “As rock at the surface gets eroded away, the material at depth gets brought to the surface,” Brantley explains. “So it’s kind of like a conveyer belt bringing it up to the surface.”

During a second sabbatical at the US Geological Survey, Brantley and White used reactive transport modeling to study soil formation from granite. “When rainwater flows through a rock, we’d like to be able to describe the chemistry of that water, how it changes as it moves through the rock. And in parallel, how does the rock change? Our approach of combining fluid flow and chemistry in a single model, that’s a very difficult thing to do.”

Discussions of chemical weathering kept resurfac- ing. Funding was hard to come by for researchers who hoped to study the rates of reactions, the rates of dissolution, the rates of soil formation, collectively known as low-temperature geochemistry. But an idea slowly emerged: “We didn’t need a spaceship; we didn’t need a telescope; we didn’t need an ocean liner. We just needed a set of observatories at the earth’s surface that could help us understand processes related to water flow, soil formation, all the processes that happen in a watershed. The sites would be strategically located along environmental gradients.”

Network of Observatories
Brantley and White envisioned an environmental gradient of observatories located around the globe in gradients of low rainfall to high rainfall, or from cold to hot climates. “There are other gradients, too,” Brantley notes, “different lithologies, different rock types, different disturbance from humans.”

In 2003, Brantley consulted with a Program Officer at the National Science Foundation to boost interest in creating the network of observatories. “We started with a very small workshop in Washington, DC, and we kept growing the idea. Eventually we started calling it “critical zone science,” using a phrase coined by Gail Ashley in a National Research Council publication to refer to the zone between the outer limits of vegetation and the groundwater.”

The name stuck. “The initiative that Art White and I worked toward has blossomed into a $40 million program at [the National Science Foundation]; all over the world, they are building critical zone observatories. It’s often associated with me, which makes me laugh because it certainly wasn’t all my doing. A lot of people really pushed for it.”
“I think the reason that idea has resonated with so many people is that it looks at the environment as one connected thing: the biology, the rocks, the atmosphere, the water. It’s a system where everything works together. And it’s so complex that we will never fully understand it. We will never be able to understand how fast it responds—and how fast processes occur—unless we work with observatories that bring us together as a team.”

Critical zone observatories aim to do just that. Researchers at critical zone observatories measure the movement of fluids in real time, but Brantley says that measurements of the solutes may help predict future changes to the critical zone. “I want to measure the solutes that they are carrying so I can see how fast a process is happening today. Then I want to relate today’s data to the geologic records of those fluxes and create a quantitative model that can bridge those two things. So you can model what’s happening today and use it to understand how that soil profile formed in the past. That gives us a much better ability to forecast how the critical zone is going to change in the future,” she explains.

Brantley’s current research focuses on critical zone research at two observatories: the Susquehanna Shale Hills Critical Zone Observatory in Petersburg, Pennsylvania, and the Luquillo Critical Zone Observatory in the mountains of northeastern Puerto Rico. As part of the Shale Hills work, she became interested in understanding the fracking of shales (5). “In my head, it’s all the same. It’s water getting into rock, moving through the rock, figuring out how fast it happens. What happens to the rock? What happens to the water? How can we understand that, and how can we quantify it?”

For Brantley, questions about the natural world help steadily unravel Earth’s most compelling mysteries.

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5 Brantley SL, et al. (2018) Engaging over data on fracking and water quality. Science 359:395–397.