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Seismic waves help scientists 'see' chemical changes beneath a watershed

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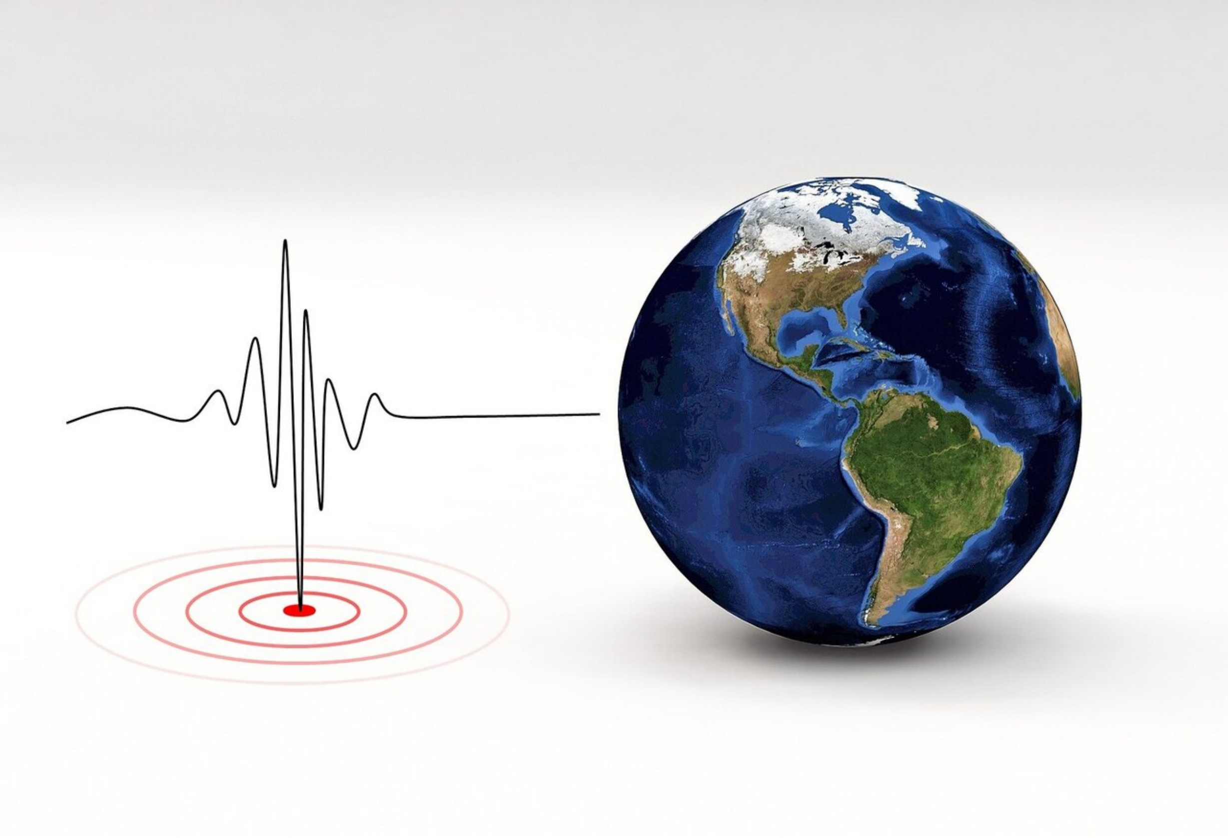

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Chemical reactions deep below ground affect water quality, but methods for "seeing" them are time-consuming, expensive and limited in scope. A Penn State-led research team found that seismic waves can help to identify these reactions under an entire watershed and protect groundwater resources.

"About one third of the U.S. population gets their drinking water from groundwater, so we need to protect this valuable resource," said Susan Brantley, distinguished professor of geosciences and director of the Earth and Environmental Systems Institute (EESI) at Penn State. "At this point, however, we don't know where the water is or how it moves in the subsurface because we don't know what is down there. In this study we used human-generated seismic waves—similar to the waves from earthquakes—to look under the surface."

Traditional geochemical tests involve drilling a borehole 3 to 4 inches in diameter deep into the ground, collecting the soil and rock samples, and grinding and analyzing the chemical makeup of the samples in a laboratory.

The process is expensive and laborious, and it only reveals the geochemical information for that specific point in a watershed rather than the entire watershed, said Xin Gu, a postdoctoral scholar in EESI.

"In this study, we had the advantage of having previously drilled boreholes, so we knew at which depths geochemical changes happen," Gu said. "We also had the materials from the boreholes, so we knew the mineral abundance and element composition. Here we tried to expand our knowledge by doing geophysics, which is relatively more efficient."

The researchers logged—lowered instruments that can send and receive signals, or even take high-resolution images, down a borehole—a 115-foot deep borehole drilled into the valley floor at the NSF-funded Susquehanna Shale Hills Critical Zone Observatory, a forested research site in Penn State's Stone Valley Forest that sits atop the Rose Hill shale formation.

Using a seismic logging tool, the researchers mapped the subsurface. The logging tool sends out a seismic wave and records the wave's velocity, or how quickly it moves, as it travels away from the tool, explained Gu. The researchers lowered the logging tool into the borehole and took measurements as it rose back to the surface. Faster velocities indicated that the waves traveled through solid bedrock or where pores in weathered rock are filled with water. Slower velocities indicated the waves traveled through weathered rock with air-filled pores, or soil near the surface.

The research team assimilated the information into a rock physics model that determined the composition change, porosity change and saturation change of the rock to explain the measured velocities.

They discovered that simple chemical reactions between water and clay caused small changes that the seismic waves could "see," according to Brantley. The changes helped the researchers understand where water opens up pores in the subsurface. They report their findings today (July 27) in the *Proceedings of the National Academy of Sciences*.

The researchers also found tiny gas bubbles in the groundwater that they speculate is deep carbon dioxide produced by microbial respiration and mineral reactions in the subsurface. Soil microbes produce carbon dioxide as a byproduct of respiration, much like humans do when they exhale. When water passes through the soil on its way to the water table, it can carry this carbon dioxide with it, Gu said.

There are two very reactive minerals commonly found in shale—pyrite and carbonate minerals, he added. When pyrite interacts with water, it oxidizes and generates sulfuric acid. The acid can interact with carbonate, a base that neutralizes the acid but generates carbon dioxide in the process. This carbon dioxide can occupy pore space at certain depths, even under the water table, explained Gu.

The researchers corroborated their results with data taken from valley and ridge boreholes drilled and logged in 2006 and 2013, respectively. They also compared it to two-dimensional models showing how velocities change in the subsurface. The 2-D models were created using seismic waves generated by striking an aluminum plate with a sledgehammer and recording the waves at many locations along the surface.

"Geophysical imaging is a quite powerful tool," said Gu. "From the boreholes, we know how velocity changes with depth, from the lab measurements on the core materials we know what the mineralogy and the geochemistry changes are with depth, and by combining that knowledge with the 2-D seismic models, we can infer how the mineralogy and geochemistry changes spatially across the watershed."

The carbon dioxide in the water does not pose a health risk, said Brantley, adding that it is exciting the researchers could "see" it with seismic waves without having previously known it was down there.

"These measurements and our ability to combine geochemical and geophysical observations will help us understand the landscape sculpted by water in the rocks beneath us," she said.

More information: Seismic refraction tracks porosity generation and possible CO2 production at depth under a headwater catchment, *Proceedings of the National Academy of Sciences* (2020). www.pnas.org/cgi/doi/10.1073/pnas.2003451117

Provided by Pennsylvania State University

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