Real-time monitoring may improve understanding of fracture dynamics

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A Marcellus Shale well site in Pennsylvania Credit: Penn State

Fractures in Earth's subsurface play an important role in our energy systems—from providing pathways to extract fossil fuel from rock deep underground to supporting emerging green technologies like carbon storage and enhanced geothermal heat—but predicting the properties of these fractures remains challenging. A new method developed by a Penn State-led team of scientists may paint a clearer picture of fractures as they open and close in real time.

"Fracture dynamics is a long-standing question in seismology, and how fractures open and close is critical for understanding this," said Tieyuan Zhu, associate professor of geosciences at Penn State. "We developed a new technique that extracts real-time information of fracture evolution, and this image can give us better physical insight than we have had."

The scientists tapped into data from seismic sensor arrays in wells around a hydrofracturing, or fracking, site in Wyoming. Fracking involves injecting water underground at high pressure to open cracks and create flow paths, often used to extract oil and natural gas trapped in rock.

One array sends out a seismic signal that travels like sound waves through the rock to pressure sensor arrays placed in nearby wells. The devices record baseline data and monitoring data, which can show changes in seismic velocity that occur during fracking, the scientists said.

"When you open a fracture, that is going to reduce the seismic speed," Zhu said. "Originally, you have one piece of rock, but when you open a fracture, you have created a pore space and you have something filling that space like water or air that is going to reduce the speed and make your waves a little bit slower."

The new analytical method allowed the researchers to view changes in the subsurface with higher spatiotemporal resolution than was possible with previous seismic methods used to characterize fractures, the scientists said.

Their findings, published in the journal *Geophysical Research Letters*, suggest a clear connection between changes in the seismic velocity recorded by the arrays and physical changes in the rock.

"The motivation for this study was to see if we could use this seismic data to distinguish when the fractures open and close," Zhu said. "We found our algorithm really can improve the resolution of what I call this image. And with this better image we can understand fracture dynamics better."

The scientists observed a small velocity reduction near the start of fracking as the pressure increased and fractures likely formed in the rock. However, they unexpectedly saw a larger velocity reduction later, after the fractures had already filled with fracking fluid.

Assisted by rock physics modeling, the scientists determined that gas bubbles trapped in a bioremediation agent added toward the end of fracking likely was responsible for the larger drop. The compound was added to treat ground contamination at the site.

"A lot of people said when you open a fracture you probably see a very big velocity change and then when you close it, you'll see a recovery of velocity," Zhu said. "But what we see is when you open the fracture, it causes a smaller change than expected and then some larger, significant velocity reduction is caused by the gas bubbles."

While further research is needed, Zhu said the method could someday help provide early warning signs of potential carbon dioxide plume leakage from carbon sequestration projects or help increase water flow between injection and production wells in enhanced geothermal systems.

"Penn State has lots of capabilities to do lab experiments with fractures—we have great researchers here," Zhu said. "Our work is really looking at the field scale. There is a big gap between the lab and field and I think our work here helps fill that gap."

More information: Xuejian Liu et al, Understanding Subsurface Fracture Evolution Dynamics Using Time-Lapse Full Waveform Inversion of Continuous Active-Source Seismic Monitoring Data, *Geophysical Research Letters* (2023). DOI: 10.1029/2022GL101739

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