Researchers explain slow-moving earthquakes known as 'slow slip events'

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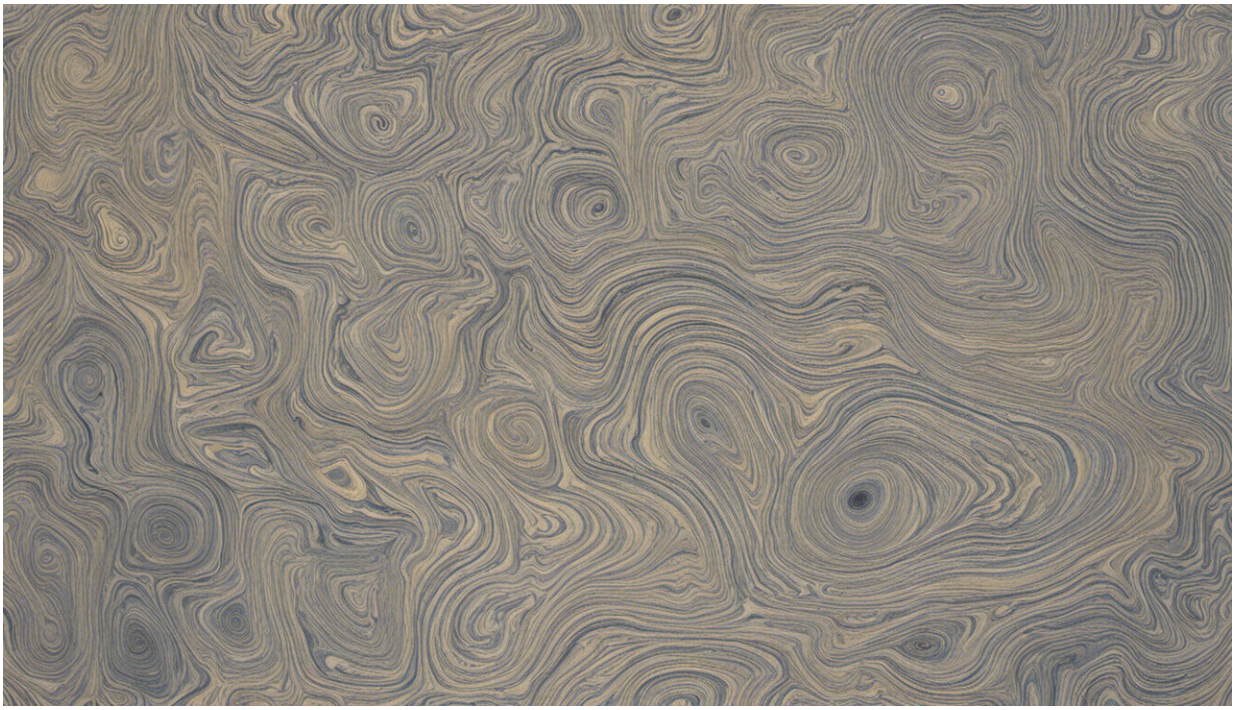

Credit: AI-generated image (disclaimer)

The Earth's subsurface is an extremely active place, where the movements and friction of plates deep underground shape our landscape and govern the intensity of hazards above. While the Earth's movements during earthquakes and volcanic eruptions have been recorded by delicate instruments, analyzed by researchers and constrained by

mathematical equations, they don't tell the whole story of the shifting plates beneath our feet.

Over the past two decades, the advent of the global positioning system—including receivers with extremely sensitive sensors that capture millimeters of movement—has made scientists aware of earthquake-like phenomena that have been challenging to untangle. Among them are so-called slow slip events, or slow-moving earthquakes—sliding that occurs over weeks at a time unbeknownst to humans on the surface.

These slow slip events occur all over the world and possibly help trigger larger earthquakes. The largest slow slip events occur in subduction zones, where one tectonic plate dives beneath another, eventually forming mountains and volcanoes over millions of years. New computer simulations produced by researchers at Stanford University and published online June 15 in the *Journal of the Mechanics and Physics of Solids* may explain these hidden movements.

"Slow slip is such an intriguing phenomenon. Slow slip events are both so widespread and really so unexplained that they're a puzzle that dangles before us as scientists that we all want to solve," said study co-author Eric Dunham, an associate professor of geophysics in Stanford's School of Earth, Energy & Environmental Sciences (Stanford Earth). "We've known about slow slip for almost 20 years and there's still not a great understanding of why it happens."

Stealthy but strong

These events are especially challenging to explain because of their unstable but sluggish nature. The fault does not slide steadily but instead, sliding periodically, accelerates, yet never reaches the point where it sends out seismic waves large enough for humans to detect.

Despite their stealthy nature, slow slip events can add up. In an ice stream in Antarctica, the slow slip events occur twice daily, last 30 minutes and are equivalent to magnitude 7.0 earthquakes, Dunham said.

Researchers think changes in friction explain how quickly rock on either side of the fault slips. With that in mind, they assumed slow slip events started as earthquakes, with a type of friction known as rate-weakening that makes sliding fundamentally unstable. But many laboratory friction experiments contradicted that idea. Instead, they had found that rocks from slow slip regions display a more stable kind of friction known as rate-strengthening, widely thought to produce stable sliding. The new computer simulations resolved this inconsistency by showing how slow slip can arise with contrary-seeming rate-strengthening friction.

"A handful of studies had shown that there are ways to destabilize rate-strengthening friction. However, until our paper, no one had realized that if you simulated these instabilities, they actually turn into slow slip, they don't turn into earthquakes," according to lead author Elias Heimisson, a doctoral candidate at Stanford Earth. "We also identified a new mechanism for generating slow slip instabilities."

Laws of physics

Dunham's research group approaches unanswered questions about the Earth by considering all the possible physical processes that might be at play. In this case, faults occur in rocks that are saturated in fluid, giving them what's known as a poroelastic nature in which the pores allow the rock to expand and contract, which changes the fluid pressure. The group was curious about how those changes in pressure can change the frictional resistance on faults.

"In this case, we did not start on this project to explain slow slip events—we started on it because we knew that rocks have this

poroelastic nature and we wanted to see what consequences it had," Dunham said. "We never thought it would give rise to slow slip events and we never thought it would destabilize faults with this type of friction."

With these new simulations that account for the rock's porous nature, the group found that as rocks get squeezed and fluids cannot escape, the pressure increases. That pressure increase reduces friction, leading to a slow slip event.

"The theory is high-level," Heimisson said. "We see these interesting things when you account for poroelasticity and people might want to use it more broadly in models of seismic cycles or specific earthquakes."

Heimisson will be creating a 3-D simulation based on this theory as a postdoctoral researcher at the California Institute of Technology.

More information: Elías R. Heimisson et al. Poroelastic effects destabilize mildly rate-strengthening friction to generate stable slow slip pulses, *Journal of the Mechanics and Physics of Solids* (2019). DOI: 10.1016/j.jmps.2019.06.007

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