Researchers gain insight into a physical phenomenon that leads to earthquakes

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Credit: Ian Kluft

Scientists have gotten better at predicting where earthquakes will occur, but they're still in the dark about when they will strike and how devastating they will be.

In the search for clues that will help them better understand earthquakes, scientists at the University of Pennsylvania are studying a phenomenon called ageing. In ageing, the longer that materials are in contact with each other, the more force is required to move them. This resistance is called static friction. The longer something, such as a fault, is sitting still, the more static friction builds up and the stronger the fault gets.

Even when the fault remains still, tectonic motion is still occurring; stress builds up in the fault as the plates shift until finally they shift so much that they exceed the static friction force and begin to slide. Because the fault grew stronger with time, the stress can build up to large levels, and a huge amount of energy is then released in the form of a powerful quake.

"This ageing mechanism is critical in underlying the unstable behavior of faults that lead to earthquakes," said Robert Carpick, the John Henry Towne Professor and chair of the Department of Mechanical Engineering and Applied Mechanics in Penn's School of Engineering and Applied Science. "If you didn't have ageing, then the fault would move very easily and so you'd get much smaller earthquakes happening more frequently, or maybe even just smooth motion. Ageing leads to the occurrence of infrequent, large earthquakes that can be devastating."

Scientists have been studying the movement of faults and ageing in geological materials at the macroscale for decades, producing phenomenological theories and models to describe their experimental results. But there's a problem when it comes to these models.

"The models are not fundamental, not physically based, which means we cannot derive those models from basic physics," said Kaiwen Tian, a graduate student in Penn's School of Arts & Sciences.

But a Penn-based project seeks to understand the friction of rocks from a more physical point of view at the nanoscale.

In their most recent paper, published in *Physical Review Letters*, the researchers verified the first fundamental theory to describe ageing and explain what happens when load increases.

The research was led by Tian and Carpick. David Goldsby, an associate professor in the Department of Earth and Environmental Science at Penn; Izabela Szlufarska, a professor of materials science and engineering at the University of Wisconsin-Madison; UW alumnus Yun Liu; and Nitya Gosvami, now an assistant professor in the Department of Applied Mechanics at IIT Delhi, also contributed to the study.

Previous work from the group found that static friction is logarithmic with time. That means that if materials are in contact for 10 times longer, then the friction force required to move them doubles. While scientists had seen this behavior of rocks and geological materials at the macroscopic scale, these researchers observed it at the nanoscale.

In this new study, the researchers varied the amount of normal force on the materials to find out how load affects the ageing behavior.

"That's a very important question because load may have two effects," Tian said. "If you increase load, you will increase contact area. It may also affect the local pressure."

To study this, the researchers used an atomic force microscope to investigate bonding strength where two surfaces meet. They used silicon oxide because it is a primary component of many rock materials. Using the small nanoscale tip of the AFM ensures that the interface is composed of a single contact point, making it easier to estimate the stresses and contact area.

They brought a nanoscale tip made from silicon oxide into contact with a silicon oxide sample and held it there. After enough time passed, they slid the tip and measured the force required to initiate sliding. Carpick said this is analogous to putting a block on the floor, letting it sit for a while, and then pushing it and measuring how much force it takes for the block to start moving.

They observed what happened when they pushed harder in the normal direction, increasing the load. They found that they doubled the normal force, and then the friction force required also doubled.

Explaining it required looking very carefully the mechanism leading to this increase in friction force.

"The key," Carpick said, "is we showed in our results how the dependence of the friction force on the holding time and the dependence of the friction force on the load combine. This was consistent with a model that assumes that the friction force is going up because we're getting chemical bonds forming at the interface, so the number of those bonds increase with time. And, when we push harder, what we're doing is increasing the area of contact between the tip and the sample, causing friction to go up with normal force."

Prior to this research, it had been suggested that pushing harder might also cause those bonds to form more easily.

The researchers found that this wasn't the case: to a good approximation, increasing the normal force simply increases the amount of contact and the number of sites where atoms can react.

Currently, the group is looking at what happens when the tip sits on the sample for very short amounts of time. Previously they had been looking at hold times from one-tenth of a second to as much as 100 seconds. But now they're looking at timescales even shorter than one-tenth of a second.

By looking at very short timescales, they can gain insights into the details of the energetics of the chemical bonds to see if some bonds can form easily and if others take longer to form. Studying bonds that form easily is important because those are the first bonds to form and might provide insight into what happens at the very beginning of the contact.

In addition to providing a better understanding of earthquakes, this work could lead to more efficient nano-devices. Because many micro- and nano-devices are made from silicon, understanding friction is key to getting those devices to function more smoothly.

But, most important, the researchers hope that somewhere down the line, a better understanding of ageing will enable them to predict when earthquakes will occur.

"Earthquake locations can be predicted fairly well," Carpick said, "but when an earthquake is going to happen is very difficult to predict, and this is largely because there's a lack of physical understanding of the frictional mechanisms behind the earthquakes. We have long way to go to connect this work to earthquakes. However, this work gives us more fundamental insights into the mechanism behind this ageing and, in the long term, we think these kinds of insights could help us predict earthquakes and other frictional phenomena better."

More information: Kaiwen Tian et al, Load and Time Dependence of Interfacial Chemical Bond-Induced Friction at the Nanoscale, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.118.076103

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