Researchers demonstrate earthquake friction effect at the nanoscale

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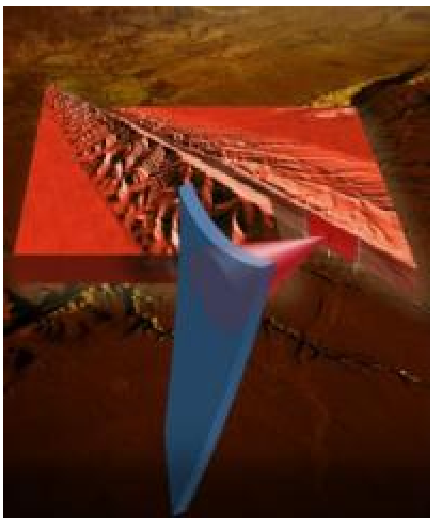

A photo illustration of an atomic force microscope probing the San Andreas fault. (Photo: D.K. Lynch)

(PhysOrg.com) -- Earthquakes are some of the most daunting natural disasters that scientists try to analyze. Though the earth's major fault lines are well known, there is little scientists can do to predict when an earthquake will occur or how strong it will be. And, though earthquakes involve millions of tons of rock, a team of University of Pennsylvania and Brown University researchers has helped discover an aspect of friction on the nanoscale that may lead to a better understanding of the disasters.

Robert Carpick, a professor who chairs the Department of Mechanical Engineering and Applied Mechanics in Penn's School of Engineering and Applied Science, led the research in collaboration with Terry Tullis and David Goldsby, professors of geological science at Brown. The experimental and modeling work was conducted by first author Qunyang Li, a postdoctoral researcher in Carpick's group, who has recently been appointed an associate professor in the School of Aerospace at Tsinghua University, China.

Their work will be published in the journal *Nature*.

The team's research was spurred by an unusual phenomenon that has been observed in both natural and laboratory-simulated faults: materials become more resistant to sliding the longer they are in contact with one another. This trait is actually fundamental to why earthquakes happen at all. The longer materials are in contact, the stronger the resistance between them and the more violent and unstable the subsequent sliding is. Energy is stored over the time the materials are in contact and is then catastrophically released as an earthquake.

While geologists, physicists and mechanics researchers have studied this phenomenon for decades, the mechanism behind this increase of friction over time has only been hypothesized. There are two main theories as to why this "frictional aging" occurs.

"One hypothesis is that points of contact deform and grow over time — that contact quantity increases," Carpick said. "The other is that bonding at the points of contact strengthens over time — that contact quality increases."

The difficulty in proving that either theory holds true lies in the fact that points of contact are necessarily embedded at the juncture of two materials and are therefore hard to observe. One of the original breakthrough experiments on these theories projected light through transparent materials held together to measure the growth of apparent contact points. While this lent credence to the contact quantity theory, there was not yet a way to assess the bond strengths at those individual points of contacts or to be sure that the observations were of single points of contacts or clusters of even smaller nanoscale contacts.

It was not until Carpick and Tullis met at a conference designed to bring physicists and mechanics researchers together with geologists that they realized that the tools of the former group could resolve the latter group's contact quality theory. The solution came from moving from the massive scale of earthquakes to the smallest scales imaginable.

"We want to simplify the case," Li said. "So in our experiment we look at only one point of contact: the tip of an atomic force microscope."

An atomic force microscope is an ideal tool for investigating bonding strength where two surfaces meet. Instead of using light, atomic force microscopes measure nanoscale details using an extremely sharp probe tip that is sensitive to the push and pull of individual atoms.

The researchers simulated rock-on-rock contact with silica, a major component in most geological materials. They pressed a silica tip against a silica surface for different lengths of time and then dragged it to measure the amount of friction it experienced. They repeated these experiments with surfaces made out of different materials: diamond and graphite. Critically, both diamond and graphite are chemically inert. As they don't easily form chemical bonds with silica, any frictional aging that occurred with them would necessarily be due to changing contact area and not increased bond strength.

The results showed a stark difference in the frictional aging between the materials.

"We saw a huge amount of aging with silica on silica. But with silica on diamond or graphite, even though the tip is experiencing about the same stress levels, we see almost no aging," Li said. "If the increasing contact area was responsible for the increase in frictional aging, you would see similar amounts in these cases. You might even see more aging with diamond because it is stiffer, leading to a slightly higher stress level in the silica, and this would cause more deformation on the tip."

The frictional aging seen in the silica-on-silica experiment was so intense that the researchers had another mystery on their hands: how to reconcile strong aging on the nanoscale with the weaker level seen on the macroscale where earthquakes actually occur.

The solution to that puzzle stems from the fact that not all contact points are created equal. Two different contact points on the same surface that are close to one another will sense each other's presence. This "elastic coupling," as it is known, means that only a few of the contact points within an area will be resisting the sliding motion at their full capacity; some will have started to slide earlier, and others will slide later. It is too difficult to make them all slide at once.

So, the overall level of resistance relies not only on the maximum resistance any contact point can provide, but also on the small fraction of contact points able to provide this resistance.

"When you take a lot of contact points,"Carpick said, "all of them could have this large amount of aging. But when you try to shear them, you see only a small fraction reach that very high value of friction at any given time. So, you need a very large effect on the level of a single contact point to get even a very modest effect on the macroscopic scale."

While showing that nansocale experiment can provide useful data for these kinds of applications was in itself an important finding for the research team, the ability to reconcile the laboratory data with geologists' observations will have a lasting effect on the field.

"If we can understand the fundamental physics," Tullis said, "then theories and equations based on that physics would have the capability of being extrapolated beyond the laboratory scale. Therefore we could use them with more confidence in all the earthquake modeling that's already being done."

"We're not ruling out the quantity argument, we're just ruling in the quality argument," Carpick said. "Future research will go to higher stress levels, where maybe contact quantity could start to come into play. We'd also like to look at different temperatures, which matter in the geological context, and do experiments where we can actually watch the contact in real time, using an electron microscope."

More information: www.nature.com/nature/journal/ … ull/nature10589.html

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