Aseismic slip as a barrier to earthquake propagation

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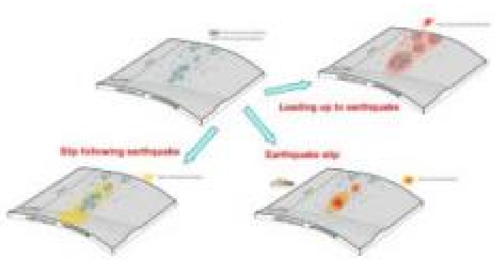


This study shows that the plate interface is a patchwork of areas differing in their frictional properties: areas with seismic, or unstable, slip (dark gray patches) and areas with aseismic, or stable, slip (light gray patches). Credit: Caltech Tectonics Observatory

On August 15, 2007, a magnitude 8.0 earthquake struck in Central Peru, killing more than 500 people—primarily in the town of Pisco, which was heavily damaged by the temblor—and triggering a tsunami that flooded Pisco's shore and parts of Lima's Costa Verde highway. The rupture occurred as the Nazca tectonic plate slipped underneath the South American plate in what is known as a subduction zone.

Soon thereafter, Hugo Perfettini—a former postdoctoral scholar with the Tectonics Observatory at the California Institute of Technology (Caltech), now at the Institut de Recherche pour le Développement in France—deployed an array of GPS stations in southern Peru. They were used to measure the postseismic deformation—the deformation that occurred in the first year after the earthquake.

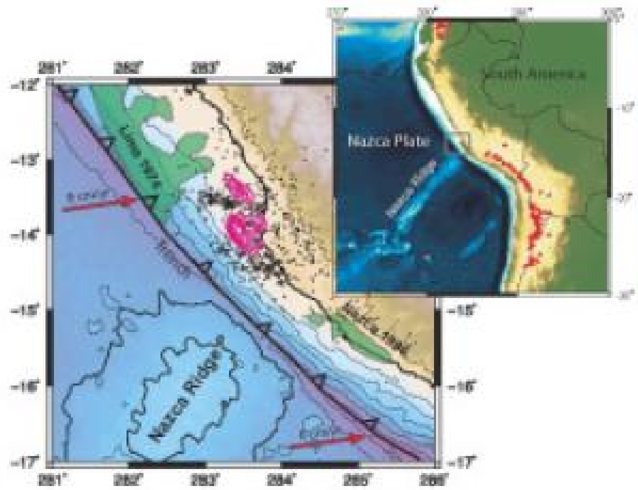
When the research team—made up of a collaboration of scientists at the Caltech Tectonics Observatory and their partners in Peru and France—looked at the data from these GPS stations and compared them to the distribution of aftershocks in the area, they noticed something "amazing," says Jean-Philippe Avouac, director of the Tectonics Observatory and professor of geology at Caltech

The team's analysis of this data—and the conclusions they were able to draw as a result—are described in a paper in the May 6 issue of the journal *Nature*.

"After the earthquake, the plate interface slipped quite a bit," Avouac says. "But the aftershocks were tiny compared to the displacement. In other words, there was a lot of deformation, but most of it was aseismic." (Aseismic slippage, or aseismic creep, is movement along a fault that occurs without any accompanying seismic waves.)

This was contrary to what had long been assumed about plate movement in the area. "We used to think the plate interface at a subduction zone—which extends in this case from the surface to a depth of about 40 kilometers—was only slipping during large earthquakes," Avouac explains. "In Peru, 50 percent of the slippage within this range of depth is actually aseismic."

When the team mapped this aseismicity, they found that it occurred in a sort of "patchwork" pattern, says Avouac, with areas that "mostly slip aseismically and areas that mostly slip during earthquakes." As it turns out, some of these areas are always aseismic, "creeping continuously," he notes—and therefore act as a sort of permanent barrier to the propagation of an earthquake. Since seismic stress cannot build up in these particular aseismic areas, there is no stress to be released in an earthquake; any seismic rupture traveling through such an area would stop dead in its tracks.



The 2007 Pisco earthquake ruptured two patches (indicated by the contour lines of seismic slip in red) of the plate interface along which the Nazca plate slides under South America at about 6 cm/yr (red arrows). The black dots show the aftershocks triggered by this quake. Two other large earthquakes had ruptured the plate interface in 1974 and 1996 (green areas). Credit: Caltech Tectonics Observatory

What was perhaps most surprising, Avouac adds, is that one of the largest aseismic areas the researchers found "corresponds with where the Nazca ridge comes into the trench."

"This large area of aseismic slip is good news," he says. "It lowers the seismic hazard in that region, and allows us to be a little bit predictive. We cannot tell you when there will be an earthquake, but we can tell you where there is stress buildup, and where there is no stress buildup. Where there is no stress buildup, there will be no seismic rupture. That is where the earthquakes are going to stop."

The lessons learned in Peru, Avouac says, should be generalizable to just about any subduction zone—Sumatra, for instance, or Chile—and probably to any other kind of fault as well. And so Avouac—along with Nadia Lapusta, associate professor of mechanical engineering and geophysics at Caltech, and postdoctoral scholar Yoshihiro Kaneko from the Scripps Institution of Oceanography, who worked on this project while doing his PhD at Caltech—decided to look at "the long-term evolution of slip on a model fault where two seismogenic, locked segments are separated by an aseismically slipping patch where rupture is impeded," they explain in a paper recently published online in the journal *Nature Geoscience*.

When the locked segments (i.e., the areas in which stress builds up, and which produce earthquakes when they rupture) are far apart—or if the intervening aseismic area has frictional characteristics that make aseismic slip easy—they "tend to rupture independently," says Avouac. If they are very close together, they tend to interact and eventually break together.

The interesting question, Avouac says, is what we can expect to happen when the two segments are close, but not too close—and are separated by an aseismic area, as was seen in the Peru patchwork. By looking at what geologists call interseismic coupling—"the fraction of sliding that is aseismic and occurs between earthquakes," explains Avouac—and by factoring in distance, time, and the sliding speed, the team was able to determine whether an earthquake that begins in one locked area is likely to stop when it hits an aseismic barrier, or whether it will be able to cross that barrier and rupture the segment on the other side.

"This model demonstrates that, based on geodetic monitoring of a subduction zone, we can not only locate the places that are accommodating plate motion through slow, aseismic slip, but also determine the probability that they will be able to arrest seismic ruptures," says Lapusta.

The hope, Avouac adds, is that this sort of modeling can be applied to data derived from actual subduction zones. "We want to create models that will take into account the physical properties of a fault to produce a scenario of how the system might evolve," he says, in much the same way that meteorologists forecast the weather.

"Our study opens the possibility of predicting patterns of large earthquakes that a fault system could produce on the basis of observations of its coupling," adds Kaneko, "and suggests that regions of low coupling may reveal permanent barriers to large earthquakes."

More information: The abstract of the Nature Geoscience paper, "Towards inferring earthquake patterns from geodetic observations of interseismic coupling," can be found at www.nature.com/ngeo/journal/v3/n5/abs/ngeo843.html

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