Putting the pieces together

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A view looking southeast along the surface trace of the San Andreas fault in the Carrizo Plain. In this image, a road has been cut going through the fault (from left to right). Image: USGS

On April 4, 2010, the ground beneath the deserts of Baja California started to rumble, then rip apart, sending tremors throughout a region 40 miles south of the U.S.-Mexico border. In the months that followed, the 7.2-magnitude quake — the second-strongest ever recorded in Baja California — triggered aftershocks that could be felt as far north as Los Angeles.

The temblor has come to be known as the "Easter Earthquake," and has been of special interest to geologists for two reasons: It is one of the most data-rich quakes on record, having been monitored by ground-based, airborne and satellite sensors; and its proximity to Southern California suggests it may have stirred up the long-dormant San Andreas Fault.

"The southern San Andreas Fault has not had a major earthquake on it since the 1600s," says Thomas Herring, professor of geophysics in the Department of Earth, Atmospheric and Planetary Sciences at MIT. "So every time there's an earthquake down in that region, everyone gets very worried that it's going to rupture northward and continue propagating up. That is a very reasonable fear."

Herring and a team of geologists recently mapped the earthquake's path in great detail, using a wealth of data including satellite images, GPS data, seismic recordings and laser altimetry. The team made some surprising findings: A much smaller tremor occurred 15 seconds before the main 7.2-magnitude shock, challenging conventional wisdom that the strength of an earthquake can be determined in the first few seconds of onset; and the main earthquake ruptured two faults, or fractures deep in the Earth, that geologists had previously thought were inactive. The group published its findings in the July 31 online edition of *Nature Geoscience*.

Stress to a fault

It's unclear exactly how the Easter Earthquake's two ruptured faults — one rupturing to the north, the other to the south — will affect the San Andreas Fault system in the short term. Geologists have observed that as an earthquake ripples through the Earth, it releases stress on some surrounding faults but increases it on others. Herring says certain structures, or "hard spots" within the Earth, may stop a quake from spreading; it's at these points, at an earthquake's edges, where stress builds back up, potentially setting the region up for the next big quake.

“Understanding how stresses in the Earth release and build up could help us understand how one earthquake sets off another over a long time scale,” Herring says. “Getting more refined at understanding these interactions is something I think we can make progress on in the next decade.”

That’s thanks in part to a growing number of earthquake-monitoring resources, particularly in quake-prone regions such as Southern California. Herring and his team took advantage of the many data resources there to draw up detailed analyses of the Easter Earthquake. The team analyzed seismic data from ground-based sensors spread throughout Southern California and nearby regions of Mexico. The sensors essentially measure the amount of shaking in the region — though Herring notes that typically within the first few minutes of a major earthquake, seismometers become “saturated,” and it’s difficult to quickly gauge the magnitude or scope of very large earthquakes from seismic data alone.

Luckily, the researchers had plenty of other information to work with. In addition to seismic data, the team pored over optical images taken from satellites — before and after the event — to literally map surface structures, such as boulders, which moved during the quake. The team matched this data with real-time GPS and radar images, retracing the earthquake’s movements.

From all that data, the researchers were able to draw up a relatively simple model of how the earthquake propagated. According to the analyses, the quake started as a small tremor along a fault, about 10 kilometers (6.2 miles) below the surface of the Earth, which connects two bigger faults. Fifteen seconds later, ruptures spread to the two adjacent faults, one rippling north, the other, south.

Brendan Meade, associate professor of planetary sciences at Harvard

University, says the combination of data showed that most of the earthquake activity occurred deep within the fault system, which would not have been obvious from surface observations alone.

"The San Andreas Fault lies at the heart of the incredibly complex Southern California fault system," says Meade, who was not involved in the research. "This paper shows that accurate characterization of the complex nature of fault systems requires not only field observations, but also inferences from remotely sensed data."

Continental unzipping

In the long term, Herring says the Easter tremor may be part of a slow tectonic ripple that will inevitably split a seam up the length of California.

"This is a relatively young area, so new faults are still forming," Herring says. "Baja California probably started opening up five to six million years ago, and since then it's sort of been unzipping, working its way up. Los Angeles will probably be toast in about 10 million years."

While little can be done to prevent continental drift, Herring says earthquake post-mortems can help a community brace against likely earthquakes in the future. In the case of the Easter Earthquake, Herring sees the results as strong motivation for strengthening "life lines" along the San Andreas Fault, to secure the water supplies, power stations and communication networks that cut across the fault.

"Everyone in Southern California is essentially just waiting," Herring says. "We know that a big, a large earthquake has to happen down there."

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