Lessons from Ridgecrest earthquake sequence

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The largest earthquake sequence in Southern California in two decades has taught scientists that large earthquakes can occur in a more complex fashion than commonly assumed. The sequence also loaded up strain on a nearby major fault, according to a new study.

The study, a comprehensive analysis of the Ridgecrest Earthquake Sequence by geophysicists from Caltech and JPL, will be published in *Science* on October 18. The Ridgecrest earthquake sequence included a magnitude-6.4 foreshock on July 4, followed by a magnitude-7.1 mainshock nearly 34 hours later, and more than 100,000 aftershocks. The sequence rattled most of Southern California, but the strongest shaking occurred about 200 kilometers north of Los Angeles.

"This was a real test of our modern seismic monitoring system," says Zachary Ross, assistant professor of geophysics at Caltech and lead author of the *Science* paper. "It ended up being one of the best-documented earthquake sequences in history and sheds light on how these types of events occur."

The team drew on data gathered by orbiting radar satellites and ground-based seismometers to piece together a picture of an earthquake rupture that is far more complex than found in models of many previous large seismic events.

Major earthquakes are commonly thought to be caused by the rupture of a single long fault, such as the more than 800-mile-long San Andreas fault, with a maximum possible magnitude that is dictated primarily by

the length of the fault. After the magnitude-7.3 earthquake that struck Landers, California, in 1992—which involved the rupture of several different faults—seismologists began rethinking that model.

As described in the *Science* paper, the Ridgecrest Sequence provides another example of how massive earthquakes can be generated by a web-like network of smaller interconnected faults that, when they rupture, trigger one another like falling dominoes. The Sequence involved about 20 previously undiscovered faults crisscrossing in a geometrically complex and geologically young fault zone.

The complexity of the rupture is only clear because of the multiple types of scientific instruments that studied the event, Ross says. Satellites observed the ruptures that reached the surface and the associated ground deformation extending out over 100 kilometers in every direction from the rupture, while a dense network of seismometers observed the seismic waves that radiated out from the earthquake. Together, these data allowed scientists to develop a model of subsurface fault slipping and the relationship between the major slipping faults and the significant number of small earthquakes occurring before, between, and after the two largest shocks.

"We actually see that the magnitude-6.4 quake simultaneously broke faults at right angles to each other, which is surprising because standard models of rock friction view this as unlikely," Ross says. "It is remarkable that we now can resolve this level of detail."

Also noteworthy is that the rupture ended just a few kilometers shy of the nearby Garlock Fault, which stretches more than 300 kilometers across Southern California on the northern boundary of the Mojave Desert. The fault has been relatively quiet for the past 500 years, but the strain placed on the Garlock Fault by July's earthquake activity triggered it to start creeping. Indeed, the fault has slipped two centimeters at the

surface since July, the scientists say.

The event, Ross says, illustrates just how little we still understand about earthquakes. "It's going to force people to think hard about how we quantify seismic hazard and whether our approach to defining faults needs to change," he says. "We can't just assume that the largest faults dominate the seismic hazard if many smaller faults can link up to create these major quakes. Over the last century, the largest earthquakes in California have probably looked more like Ridgecrest than the 1906 San Francisco earthquake, which was along a single fault. It becomes an almost intractable problem to construct every possible scenario of these faults failing together—especially when you consider that the faults that ruptured during the Ridgecrest Sequence were unmapped in the first place."

The Science paper is titled "Hierarchical interlocked orthogonal faulting in the 2019 Ridgecrest earthquake sequence."

More information: "Hierarchical interlocked orthogonal faulting in the 2019 Ridgecrest earthquake sequence" *Science* (2019). science.sciencemag.org/cgi/doi … 1126/science.aaz0109

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