U.S.

Artificial Intelligence Helps to Decode Mysterious Earthquake Swarms

Seismologists use software to uncover complexity of fault systems; work could yield insights into how earthquakes originate

MY CONTRIBUTION:
For this article I produced the map and two scatter plots. The map was created in QGIS and fine-tuned in Illustrator to match WSJ style. The plots were both developed in an Observable notebook with D3.js and pulled into Illustrator to be cleaned.

Live link:
https://www.wsj.com/articles/artificial-intelligence-helps-to-decode-mysterious-earthquake-swarms-11592998200

A strong earthquake in Croatia on March 23 caused widespread damage, injured more than 20 people in the capital, Zagreb, and was followed by a series of aftershocks.

PHOTO: DARKO BANDIC/ASSOCIATED PRESS

By Daniela Hernandez | Graphics by Sawyer Click and Alberto Cervantes

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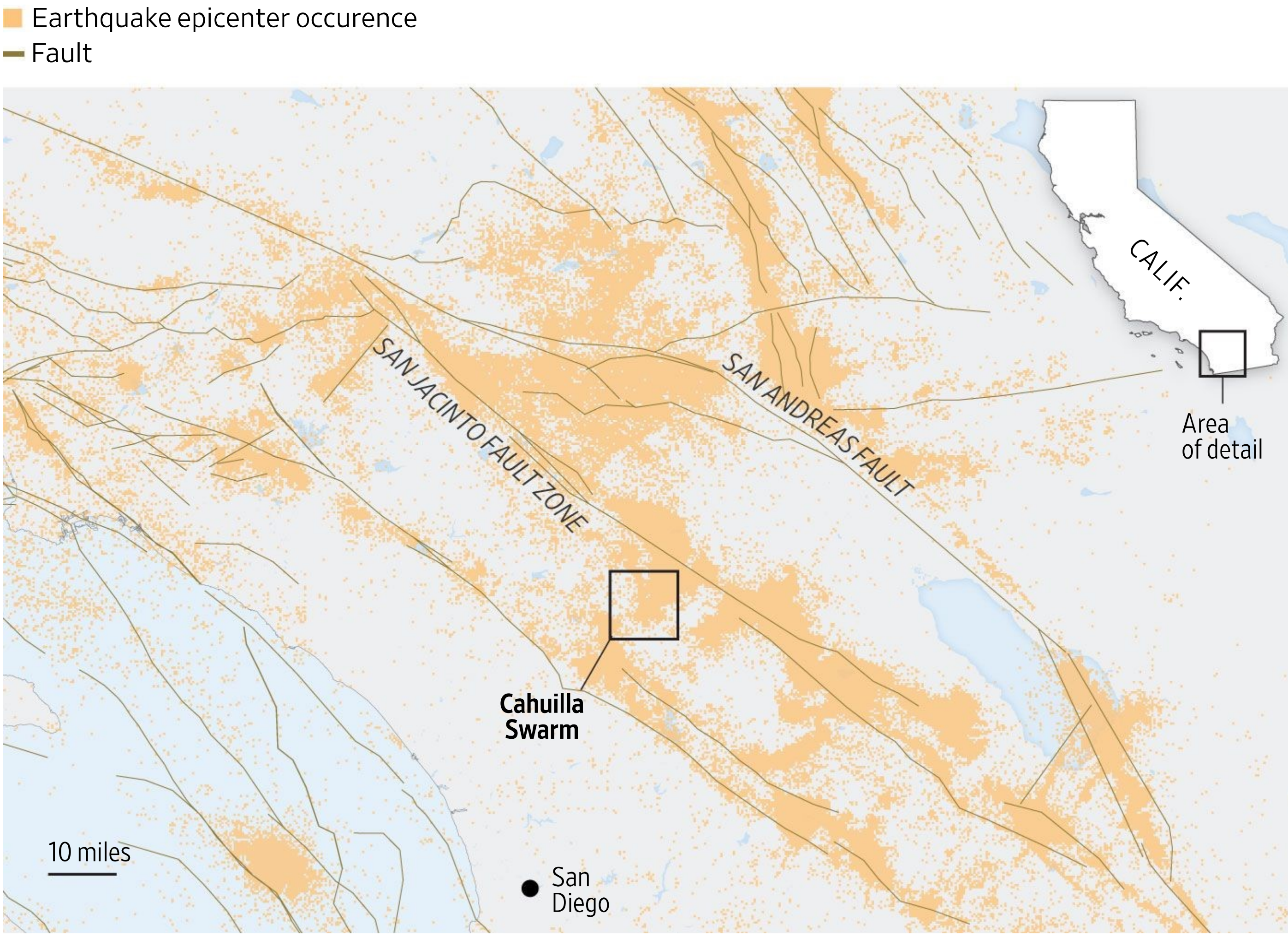
In 2018, seismologists at the California Institute of Technology got several emails asking about a flurry of small earthquakes near Cahuilla in Southern California. What was going on underground? How long might the tremors last?

The scientists started looking at data streaming in from satellites, plus a variety of sensors that measured earthquake intensity and the deformation of the earth's crust, according to Elizabeth Cochran, a U.S. Geological Survey seismologist working with Caltech. The initial analysis came up empty.

Earthquakes in the Region, 2016-19



Source: Zachary Ross, California Institute of Technology

That is when Zachary Ross, a Caltech seismologist who specializes in applying artificial intelligence to earthquake data, decided to input the measurements into an AI algorithm he had written.

The software yielded one of the most detailed descriptions to date of so-called earthquake swarms—unpredictable strings of quakes, often low-intensity—across time and space.

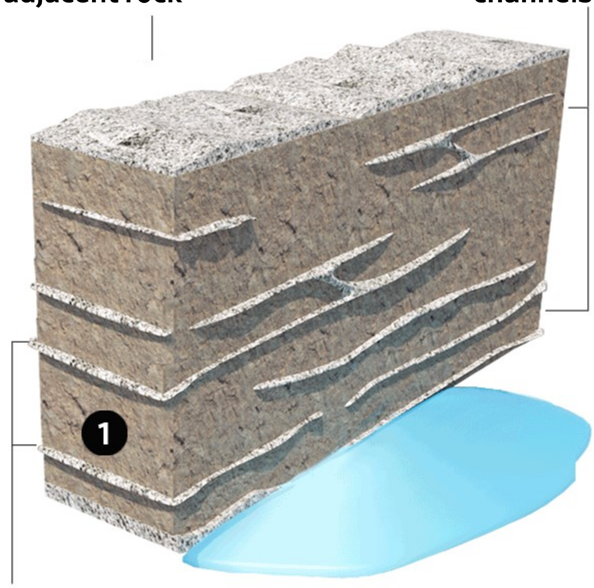
The analysis, described in a study published this month in the journal Science, could help scientists better understand the complex set of dynamic processes underground that culminate in earthquakes, seismologists said.

The earthquakes people are most familiar with, including Tuesday's 7.5-magnitude quake off the Pacific coast of Mexico that rattled the country's capital, happen when two tectonic plates slip past each other.

The Makings of an Earthquake Swarm

As fluid fills a fault zone, it makes it easier for slabs of rock to slip.

1. The rock in the fault zone is porous, like a sponge
2. At the base, there is an underground reservoir of fluid that's initially sealed



3. A crack allows that fluid to seep into the fault
4. The fluid acts as a lubricant that makes it easier for the fault to slip

Source: Science Magazine

In reality, that explanation is an oversimplification of what is happening beneath our feet, said Angela Chung, an earthquake early-warning system project scientist at the University of California, Berkeley's Seismology Lab. The behavior of fault zones, where earthquakes originate, is much more complex, but researchers still have little insight into the geological processes that give rise to that complexity, she and other experts said.

Unlike aftershocks—events following a single large earthquake that decrease in frequency and intensity with time—swarm activity is usually very erratic. Scientists often describe swarms as mysterious and elusive. Each one is unique.

They tend to happen where the ground is warm—near volcanoes, for instance. The consensus is that earthquake swarms are a byproduct of other geological processes, scientists said, including the movement of water, magma or gases underground and aseismic slip, the creeping movement of faults too slow to cause shaking.

"It's not really clear why [earthquakes] happen exactly," said Dr. Chung, who wasn't involved in the swarm work. "It can be a useful step to understand what starts an earthquake sequence."

The Cahuilla swarm described in the Science study originated along a 330-foot cracked region roughly 5 miles below the surface and 9 miles from one of

California's major fault zones.

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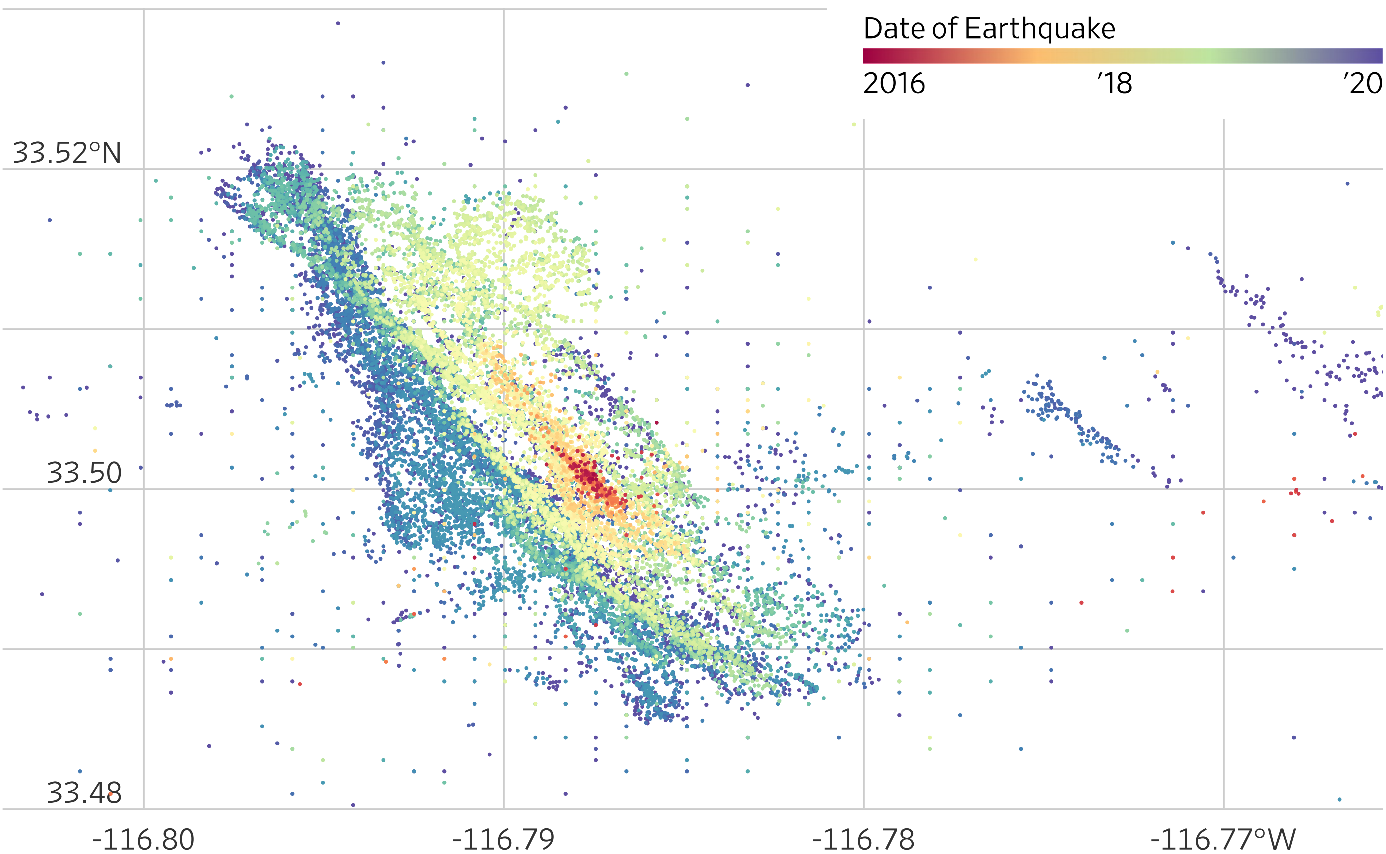
Have you experienced an earthquake? Share your story below.

The swarm started in 2016 and lasted roughly four years, radiating out from this original spot to extend over an area of roughly 6 square miles. Its duration was far longer than other swarms recorded with modern tools, the authors said.

Where the Cahuilla Swarm Spread

The swarm started in 2016 and lasted roughly four years, radiating out from an initial point (red) to extend over an area covering roughly 6 square miles.



Source: Zachary Ross, California Institute of Technology

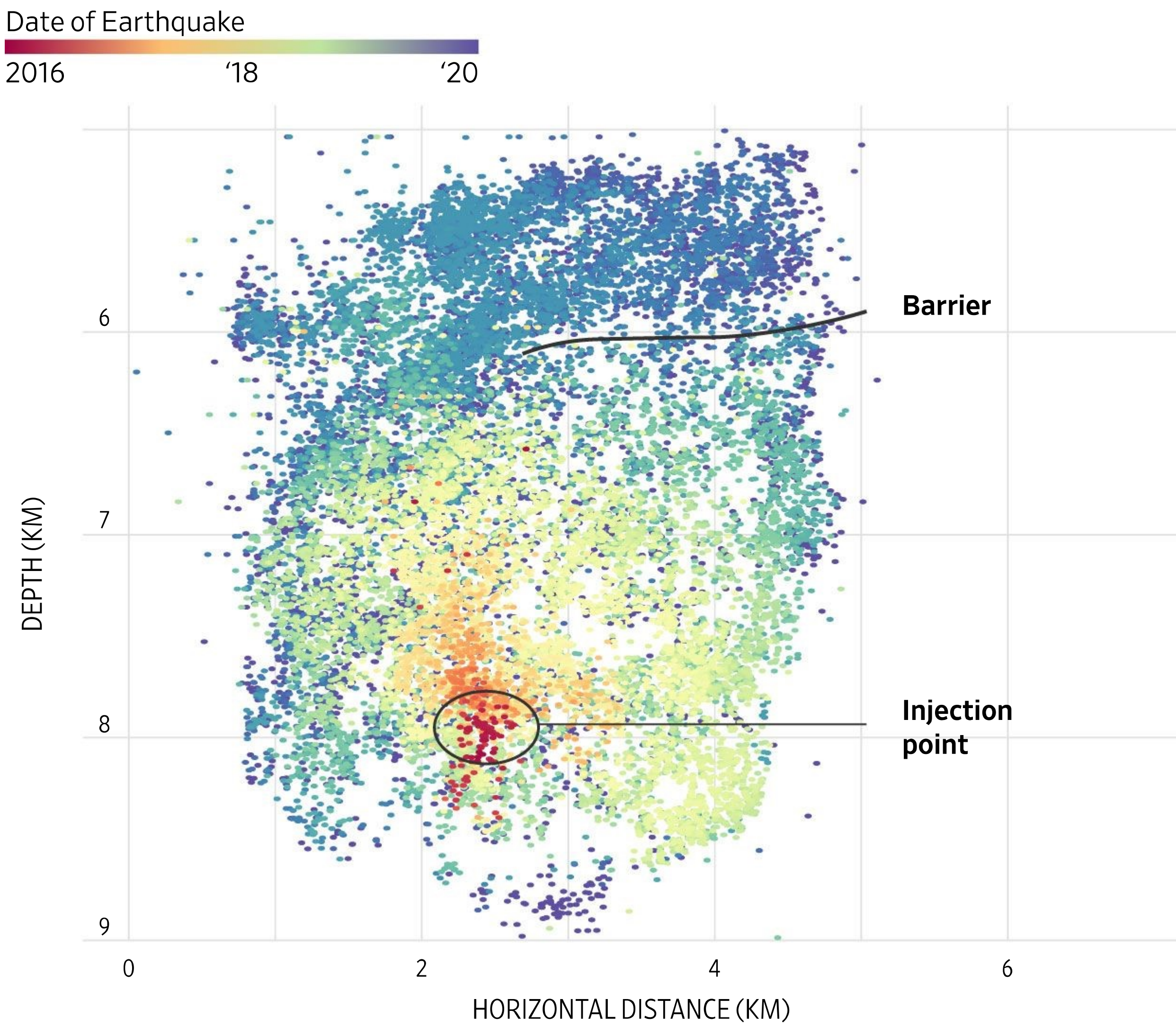
A fracture in the porous rock below allowed an unknown fluid—perhaps water or a gas—to migrate up and fill in the gaps, as water fills the holes in a sponge, Dr. Ross said. The fluid, which migrated along the fault zone, acts as a lubricant that makes it easier for adjacent slabs of rock to slip past one another. When they do, that generates earthquakes. The larger the slip, the bigger the quake's magnitude.

Dr. Ross's AI system scanned earthquake recordings, logged the time the temblors occurred and pinpointed their locations. The software detected more than 22,000 earthquakes ranging from magnitude 0.7 to 4.4. They were mostly tiny and imperceptible, both to humans and less-sophisticated methods of analysis, according to the authors.

"These smaller earthquakes are happening all the time, which means they're filling in gaps between all the larger ones," said Dr. Ross. "It's connecting the dots better."

Underground Cross-Section of the Cahuilla Swarm

A fracture in the rock allowed fluid to migrate up (injection point). Less fluid flowed into sections of the rock that were less porous, decreasing the chance of earthquakes (barrier zone).



Note: The horizontal and vertical axes are not proportional.
Source: Zachary Ross, California Institute of Technology

That is important because seismologists don't fully understand the geological recipe of events that leads to large earthquakes.

"Every time there's a large-magnitude earthquake....they always seem to surprise us," said Alicia Hotovec-Ellis, a volcano seismologist at the USGS's California Volcano Observatory, who studies volcanic earthquake swarms but wasn't involved in the new study. "Being able to resolve some of these heterogeneities in the fault structure and places where slip is allowed to happen might be really useful in trying to anticipate what shaking might look like for earthquakes in the future."

The use of AI in seismology is still new, but interest is growing, scientists said. The researchers plan to study other previously recorded swarms to understand how long they last and what geological events caused them.

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