The Ridgecrest earthquakes: Torn ground, nested foreshocks, Garlock shocks, and Temblor's forecast

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A new image of the ground deformation, a rich and enigmatic foreshock sequence, aftershock trends we can explain, and others that are more elusive. This is also the time see how Temblor app's hazard forecast for Ridgecrest fared.

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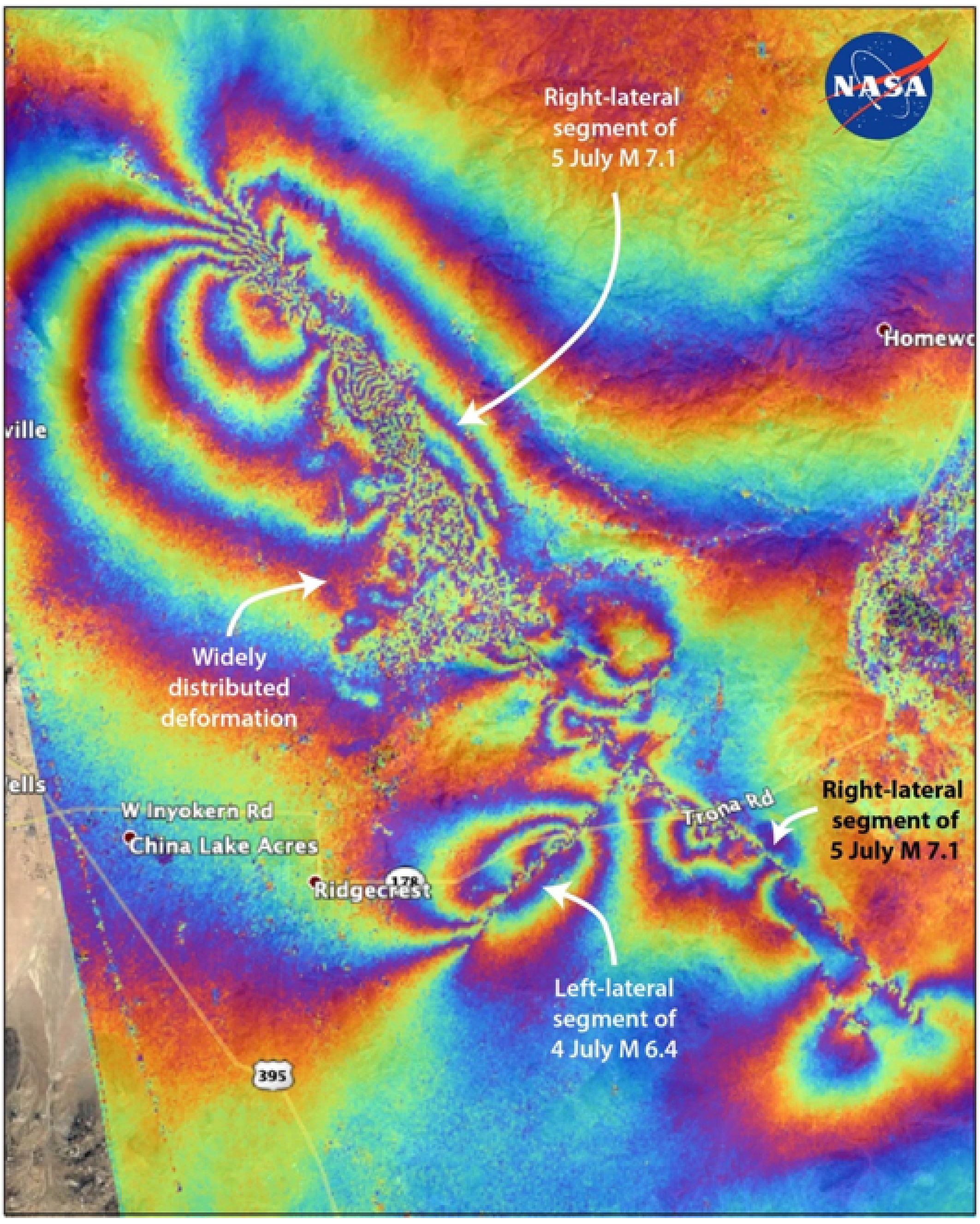
For a note on what to do during an earthquake (re: Jimmy Kimmel's segment), see the end of this article.

Ground Deformation from Space

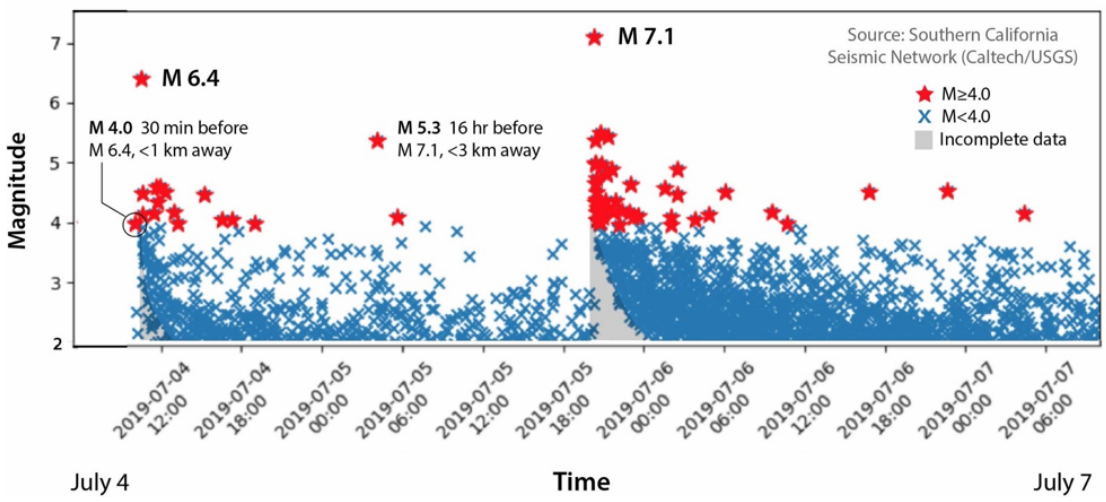
The Advanced Rapid Imaging and Analysis (ARIA) team at NASA JPL and Caltech just released this Interferometric Synthetic Aperture Radar (InSAR) image that shows how the fault slip in the 4 July M 6.4 and 5 July M 7.1 earthquakes warped the earth's surface. We have annotated the map to highlight its remarkable features: knife-edge faulting in the south, and what looks like a distributed band of shear in the north. That broad pattern of deformation may explain why geologists had missed the fault in the first place: it may masquerade as several small, discontinuous tears at the surface. By using this image and others like it that will come in as more radar satellites pass over the Ridgecrest area, we can study how the slip in these earthquakes was distributed at depth, why the fault may have slipped that way, and what that might mean for how earthquakes occur in general.



The interferogram is derived from the ALOS-2 satellite, operated by the Japan Aerospace Exploration Agency (JAXA), with images taken before (16 April 2018) and after (8 July 2019) the earthquakes. Each color cycle represents 11.45 cm (4.5 inches) of ground displacement in the radar line-of-sight (28° from vertical and roughly east).

Foreshocks of foreshocks

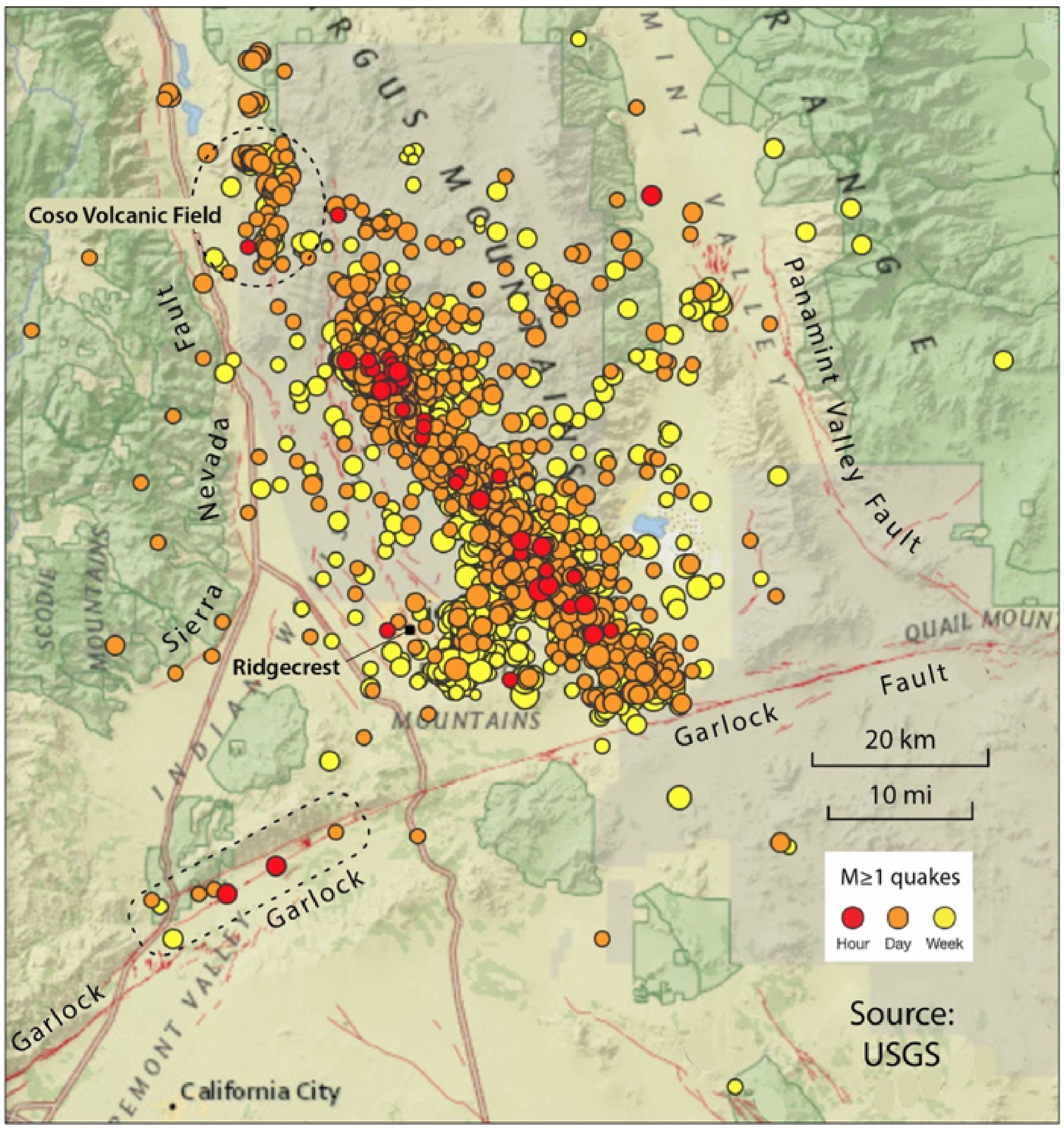
When we look how the earthquake sequence unfolded in time, we see what we might call 'nested foreshocks.' First, a M 4.0 struck 30 min before the M 6.4 mainshock in virtually the same location. Rare, but not unprecedented. About 18 hours into the M 6.4 aftershock sequence, the largest aftershock, a M 5.3 event struck. Then, about 16 hours later, the M 7.1 ruptured less than 3 km from the site of the M 5.3. That's also rare. But while fascinating, we don't see much that marks those little shocks for future greatness.



Here are the quakes in time. This plot is preliminary, as the locations will ultimately be improved, and many of the small quakes that struck soon after the mainshocks will be recovered. Thinking about this sequence was inspired by Derek Watkins from the New York Times.

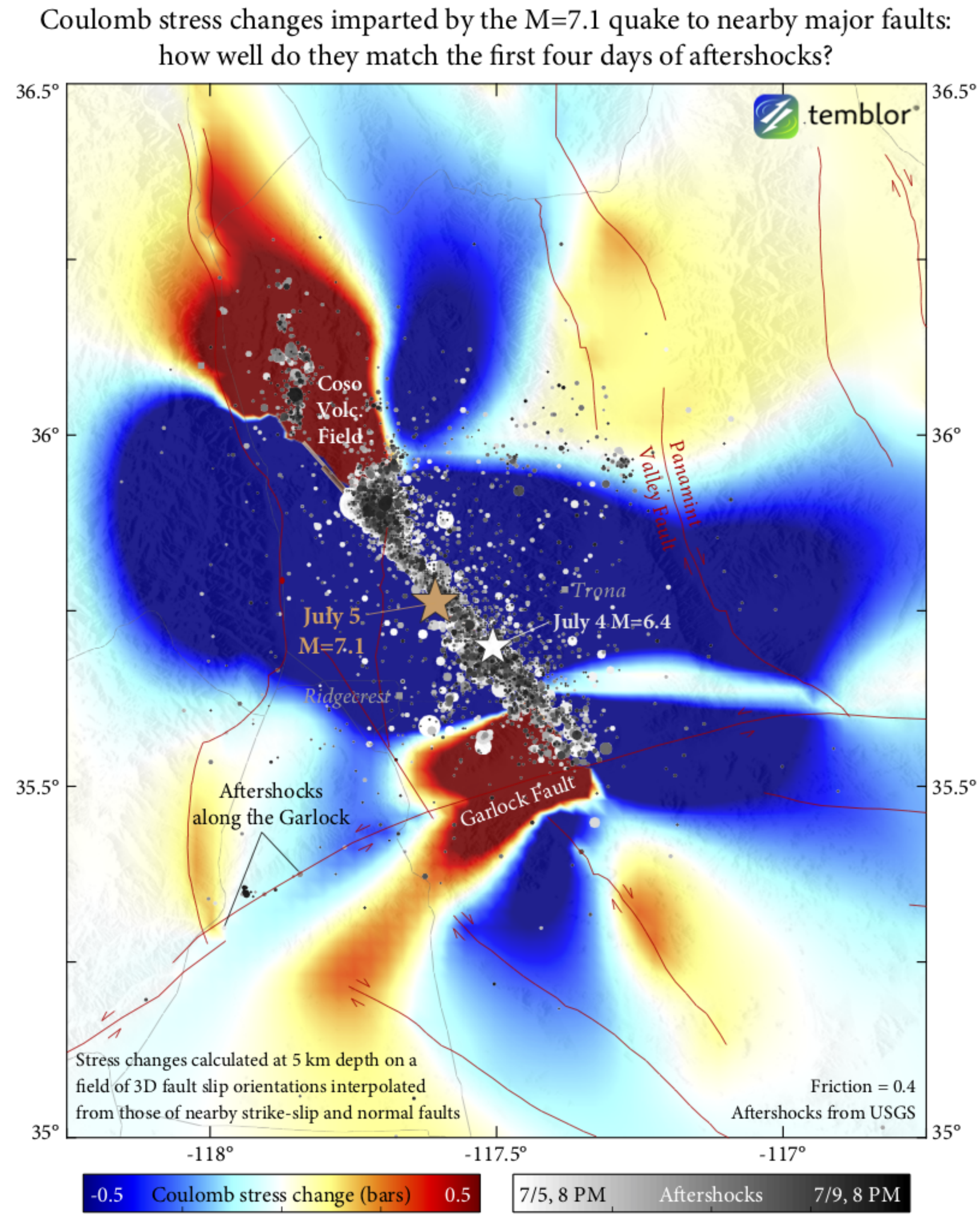
Aftershocks in the Coso Volcanic Field and on the Garlock Fault

The Coso Volcanic Field, an area northwest of the earthquake with a history of seismic swarms, has lit up in earthquakes since the 7.1 quake. Over the past 48 hours, aftershocks have also begun to show up along parts of the Garlock Fault to the southwest. Can we explain these observations?



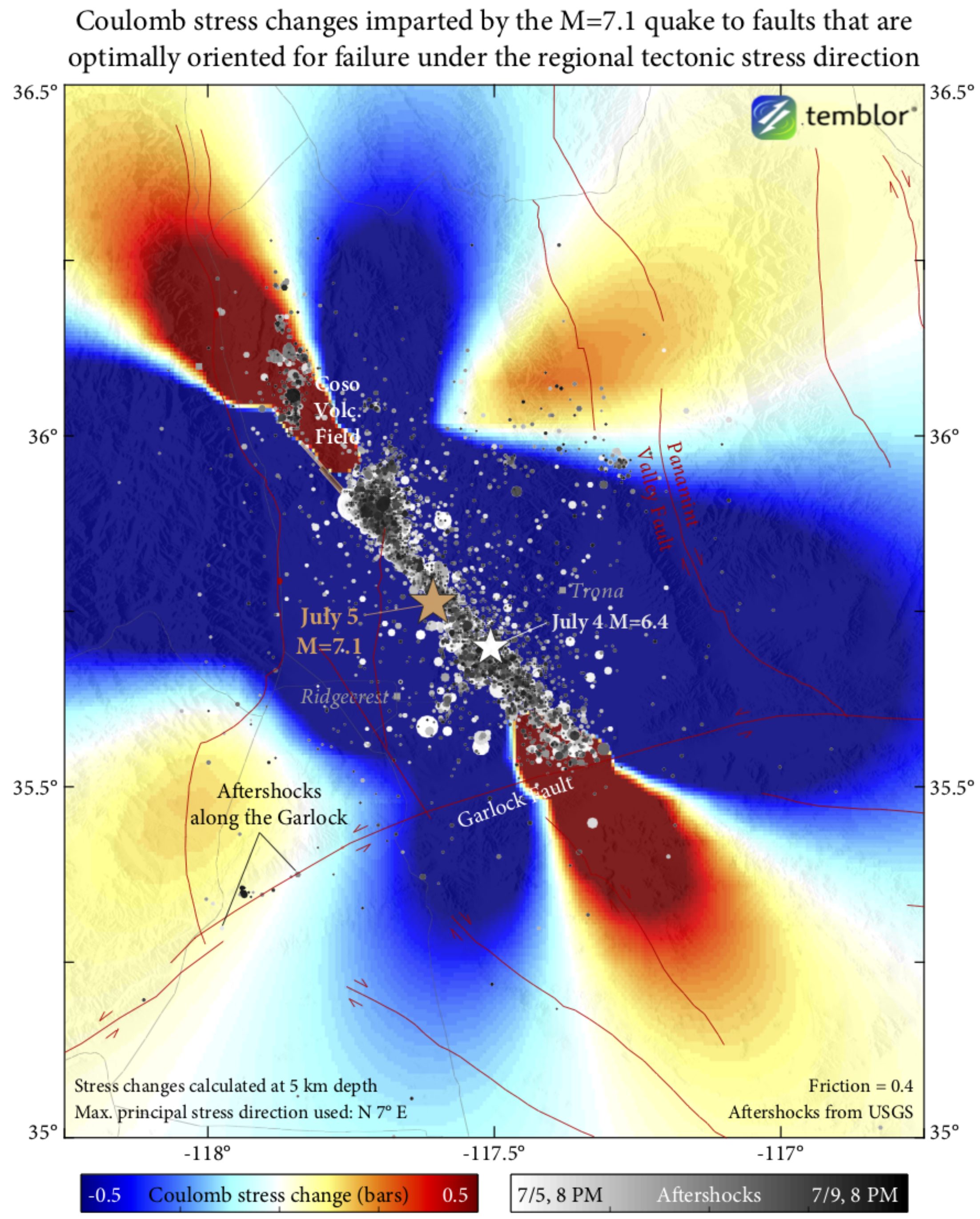
One can see 8-10 small shocks on the Garlock Fault (lower left), and a large cluster at Coso Volcanic Field (upper left).

When an earthquake ruptures a fault, it warps the surrounding earth (as captured by the satellite image above) and therefore changes the state of stress in the earth around it, including along nearby faults. These stress changes can push some faults closer to failure and pull others further from it, depending on where they are with respect to the earthquake. In the plot below, we used the USGS slip model for the M 7.1 shock to calculate what it might have done to the major mapped faults in the region and others oriented like them. All else being equal, we would expect aftershocks to be more numerous around faults brought closer to failure by the stress changes in the M 7.1 earthquake (the red zones below), and less prevalent along faults inhibited from failure (the blue 'stress shadows').



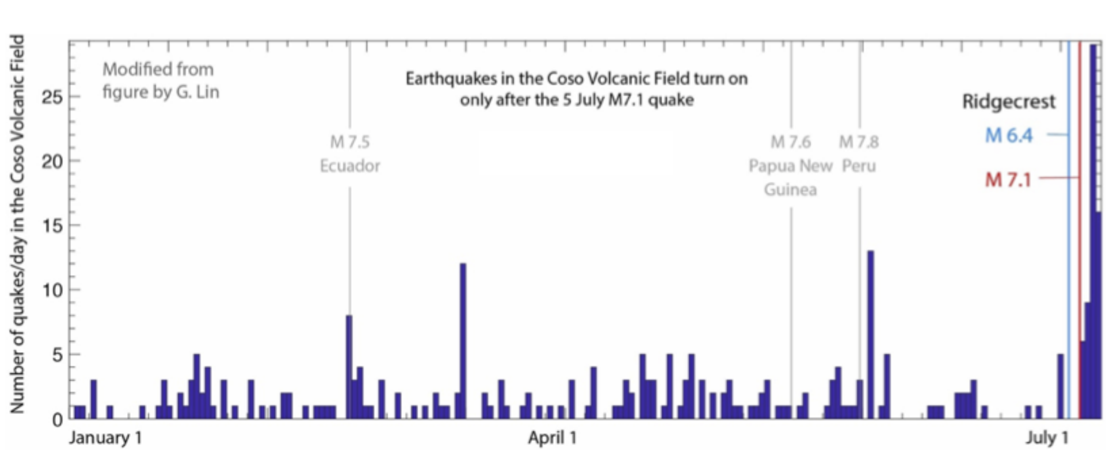
Faults in the red lobes are calculated to be brought closer to failure; those in the blue 'stress shadows' are inhibited from failure. The calculation estimates what the dominant fault orientations are around the earthquakes by interpolating between major mapped faults (shown in red lines). So, we would expect strong stressing in the Coso Volcanic Field to the north (where the aftershocks lie), and along the Garlock Fault to the south (but not where most of them lie).

We see that the the 7.1 quake likely brought faults in the Coso Volcanic Field closer to failure, consistent with the abundant aftershocks there. But although the quake also strongly increased the Coulomb stress on a 30-km (20-mile) stretch of the Garlock, most of the aftershocks along the Garlock have in fact appeared in a blue zone to the southwest. Satellite radar imagery spanning several years before these quakes suggests the Garlock may be slowly creeping in the blue zone [Tong et al., 2013], which if real could play into seismicity there, but that signal is within the noise level of the dataset. Satellite radar imagery and other geodetic (surface deformation) data and field observations will help piece together what has been going on, not only near the Garlock but everywhere in and around the Ridgecrest sequence.



This calculation differs from the one above in that the stress changes are calculated on faults that are perfectly oriented for failure under the regional stress direction, which is north-south compression and east-west extension.

It is also possible that some of those aftershocks to the southwest didn't actually occur on the Garlock, but instead on smaller nearby faults that are more optimally oriented for failure under the current tectonic stressing that drives the Eastern California Shear Zone. (The Garlock, for its part, has been rotated severely out of alignment with the regional stress direction, so exactly how much and how often it still slips is a topic of ongoing research.) The above plot shows that faults with this more optimal orientation would have in fact been slightly promoted for failure by the Ridgecrest quake down around where those aftershocks are occurring. We see that faults oriented like this in the Coso region would also have been in the red.

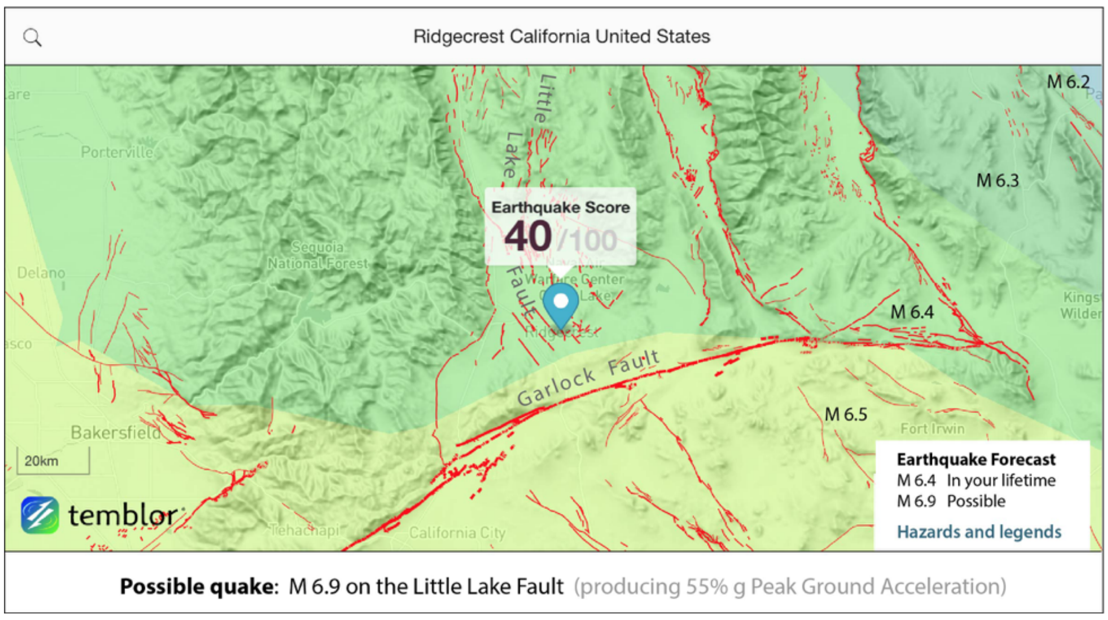


Time history at Coso shows a mystery: The M 6.4 shock had no effect, but the M 7.1 produced abundant shocks.

A closer look at Coso shows that, intriguingly, it was quiet after the M 6.4 4th of July earthquake, but began to light up in earthquakes as soon as the M 7.1 hit on July 5. That might be because the 7.1 was a much larger earthquake and induced larger Coulomb stress changes there; it might alternatively (or also) be because the throughgoing seismic waves from the 7.1 shook Coso harder. We note that a M 7.5 earthquake in Ecuador earlier this year may have also been correlated with a temporary uptick in seismicity in Coso, but two other large remote earthquakes don't look like they were. This effect, called remote triggering, has been observed in various parts of the world following several large earthquakes in the past 25 years, but studies differ on whether it is characteristic of the Coso region [Castro et al., 2017; Zhang et al., 2017]. Nevertheless, with more in-depth research, we can use the Ridgecrest sequence and Coso aftershocks as a natural experiment that helps shed light on what controls earthquake behavior there – and therefore what may control it in general.

How useful was Temblor in offering guidance to Ridgecrest residents?

Temblor gives three condensed forecasts in one screen. Here it is, slightly annotated:



Temblor app screen for Ridgecrest, California (app.temblor.net/)

– **Earthquake Score is 40**, which is based on the most current 'probabilistic' USGS model. A score of 100 means probable damage of 20% of the replacement cost of a home in 30 years. The score factors in all quakes large and small, near and far, and the amplification of shaking in basins. For comparison, the score is 65 in downtown Los Angeles, and 95 in San Bernardino.

– **Lifetime quake is M 6.4.** This is the earthquake magnitude that has a 1% chance per year of occurring within 60 mi (100 km); that's a 60% chance of occurring if you live to 90. It was certainly exceeded, and this tells us that a M 7.1 here is rare. The lifetime quake is M 6.7 for L.A., and M 6.8 for San Bernardino.

– **Possible quake is M 6.9.** Temblor finds the USGS 'scenario' earthquake that produces the strongest shaking at your location and reports its magnitude, fault, and the shaking. Temblor then estimates the cost of repairing the damage to your home in this quake, based on your home's characteristics. For L.A., it is M 7.0, and for San Bernardino, it is M 7.7. Although the shaking estimate is for a nearby fault with a lower magnitude, it turns out to be spot on: The forecast peak shaking was 55% g (55% of the force of gravity) and the observed was 57%.

Why do we give you two quake magnitudes? (in this case, M 6.4 and M 6.9)**.** The first is the quake size you will more likely than not experience in your lifetime, the second is the largest that the USGS considers possible at your location. On July 5, both were exceeded, but the forecasted shaking nevertheless turned out to be prescient.

In short, while earthquakes will continue to surprise us, their shaking doesn't have to. Take this opportunity and understand your risk.

A note on what to do when the earthquake strikes (and when you get a ShakeAlert alert)

Jimmy Kimmel got it almost right – the "triangle of life" idea is indeed wrong and doorways aren't all that great – but you should still definitely get under a table or desk in an earthquake, if one's close by. That's never changed, and it's a key part of "cover" in drop, cover, and hold on. Check out Dr. Lucy Jones' interview on Conan –

she shows a picture from the 1985 Mexico City earthquake of a concrete ceiling that collapsed but was held up by a few school desks. That's why getting under a table or desk is such a good idea.

References

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Fulkth • 10 days ago

Is it odd that there is a gap between the main fault shocks and the Coso volcanic field circled? The gap is where the current Coso Geothermal Plant is located and the hottest area closest to the surface. Is the rock hot enough there to slip without major earthquakes?

4 • Reply • Share ›

Ross Stein Mod → Fulkth • 8 days ago

Good point. The cluster of shocks in the Coso Volcanic Field probably behave differently because the Field is infused with steam and gas given off by the magma below. So, faults are effectively more lubricated, and it seems more responsive to stress. But Guoqing Lin (Univ Miami) and Debi Kilb (UCSD) are watching this closely, and will write another post if the situation changes or they have a better explanation.

2 • Reply • Share ›

Kareem J. Lanier → Fulkth • 8 days ago • edited

I believe that area is considered a geothermal area, much like Cloverdale, California.

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Soda pop • 9 days ago

OK explain this please.How come you scientists all tell us this is normal or we are way over due when i researched earthquakes occurring in pairs simultaneously . There are little incidents of two or more earthquakes occurring on the same fault line all of which's aftershocks subsided within 24-48 hrs.However in California we are seeing incidents of 2 or 3 earth quakes all happening with in seconds of each other through out the whole day. They all measure differently on scale as well you need to explain in further depth about the discrepancy concerning the liquefaction numbers in Ridge Crest any one with common sense can see something very peculiar especially near china lake.I think also the subduction in Alaska in addition to the spike of activity along the entire oceanic tectonic plate system indicates these are linked in some way maybe its just the beginning of something cataclysmic or maybe i am over reacting.

1 • Reply • Share ›

Kareem J. Lanier → Soda pop • 8 days ago

Actually, earthquakes rarely occur as solo events. They are usually part of some sequence or series of quakes. Different regions can see a variety of earthquake sequences. Having lived in the San Francisco Bay Area, I have experienced much seismic activity up here and have carefully watched seismicity in other parts of California. I have one PS-2 recording system as well as one digital seismic recorder. So I have seen many earthquakes. Other than isolated quakes that occur in places like San Pablo, Richmond along the Hayward Fault versus an area near Kensington/Piedmont along the same fault. The two can vary quite a bit.

In 1992, Landers and Big Bear saw two different earthquake sequences and many, many aftershocks. Socal has many examples of areas where faults can intersect and create bilateral ruptures or occur along single primary faultlines. And even then, you could have a sub-parallel fault rupture that triggers other quakes in other regions even hundreds of miles away. We say this with the Hector Mine quake which triggered quakes in Nevada. So, it's an intriguing phenomenon but it certainly isn't unusual.

1 • Reply • Share ›

Soda pop → Kareem J. Lanier • 17 hours ago

I understand that much. I've taken a closer look at the situation. You're right however my main concern is is it not odd that coso junction is under going dramatic change. I know it is one of the most active seismic regions in the States, so why so much load. Mean while the minimum threshold " that the medium is significantly thicker in San Bernardino. in a normal model of earth the seismic waves traveling along the crust take longer than the ones that diffract off the mantel called the direct path. So if a 7.1 occurred in California and you were in Texas shouldn't you be able to detect the direct paths well before any instruments used to measure the shake. In normal circumstances we observe phantom shocks that tell us a P +S combo wave is coming see-its foot print aftershocks reverberate at a rarely do they when bubbles come out of the lithosphere. That didn't happen they didnt even receive those Phantom waves at all in many places on the North American Plate. In all cases of the Plates they're instruments measured its existence well before the P waves shows up.Something is delaying or even redirecting the energy. So that has got to tell only one thing. A cone of highly condensed molten rock is accumulating beneath the crust creating a cone of raising pressure. Le Brea Tar Pits and many other spots of california in this feed show high pressence of S waves but look at one of the most active spots coco is silent not normalTaking into consideration how active the oceanic tectonic plates have been since April 2019 from California, Alaska,Japan and Singapore " which in it itself is very normal however the fact that 80 percent of the entire globes seismic activity since april has been over looked.Despite the geologist telling you it all OK. Imagine what the body of water with in the boundaries of the Juan de Fuca Plate, Pacific Plate and the Philippine Plate crusts meet the water. Now Imagine Earth Quakes ranging from 3.0-7.3 mag. occurring some where roughly every 30 seconds. And Indeed as I was Writing this any where ranging from 5-8 earthquakes have took place along this path. But not much any where else on the globe.So my predictions are this for the next week the energy will bounce forth from Philippians Tectonic Plate and The North American Plate would make the weak link buckle in and collapse that is the that will asseverate the integrity of Juan de Fuca Plate, for a very near future event which in terms of the planet the formation of a new giant cauldron and eruption of yellow stones , but still not enough for the big one so we'll be fine least for a few more centuries hopefully.

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Brian Ferwerda • 2 days ago

Geologist and Ridgecrest resident here, though I was in Idaho when the larger quakes hit. I have a question. All the offsets I've seen on the NE-SW trend (which I am currently assuming is related to the 6.4 event) are left lateral. I've checked out a large section of the southernmost rupture on the NW-SE trend (assuming 7.1) and I've seen up to 3 feet of right lateral displacement. Given these fault orientations, and that they seem to intersect, these senses of motion seem incompatible. If it was a block rotation, I would expect the faults to have the same sense of motion. Am I missing something here?

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Ross Stein Mod → Brian Ferwerda • a day ago • edited

The longer NW-striking fault is right-lateral, the shorter SW-striking fault is left-lateral. So, as you point out, it's not block rotation. Instead, slip on both adjoining faults accommodate N-S contraction and E-W extension that drives all of the faulting in the Eastern California Shear Zone. Still, while not unprecedented, the 90° angle between the faults is puzzling, and implies very low fault friction on both to slip at once.

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Fred Turner • 2 days ago

Chris, Ross, Guoqing and Deborah, Recorded Sa1 values are significantly higher SE of the epicenter compared to NW. Is there a known relation between the knife-edge rupture to the SE versus the distributed band of shear to the NW that would explain the differences in Sa1 values? Also can you comment on the spectral and regional variations of ground motions in Ridgecrest and how that might help explain the observed patterns of damage?

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Ross Stein Mod → Fred Turner • 2 days ago

['Sa1' is the spectral acceleration at a period of 1 sec, a measure

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