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M 7.1 SoCal earthquake triggers aftershocks up to 100 mi away: What's next?

POSTED ON JULY 6, 2019 BY CHRIS ROLLINS, PH.D.; MICHIGAN STATE UNIVERSITY

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The 50-km-long rupture has triggered widely dispersed aftershocks. However, almost none of these struck on the faults that the M 7.1 brought closer to failure: The major Garlock Fault; or the Blackwater, Panamint Valley, or Sierra Nevada Faults.

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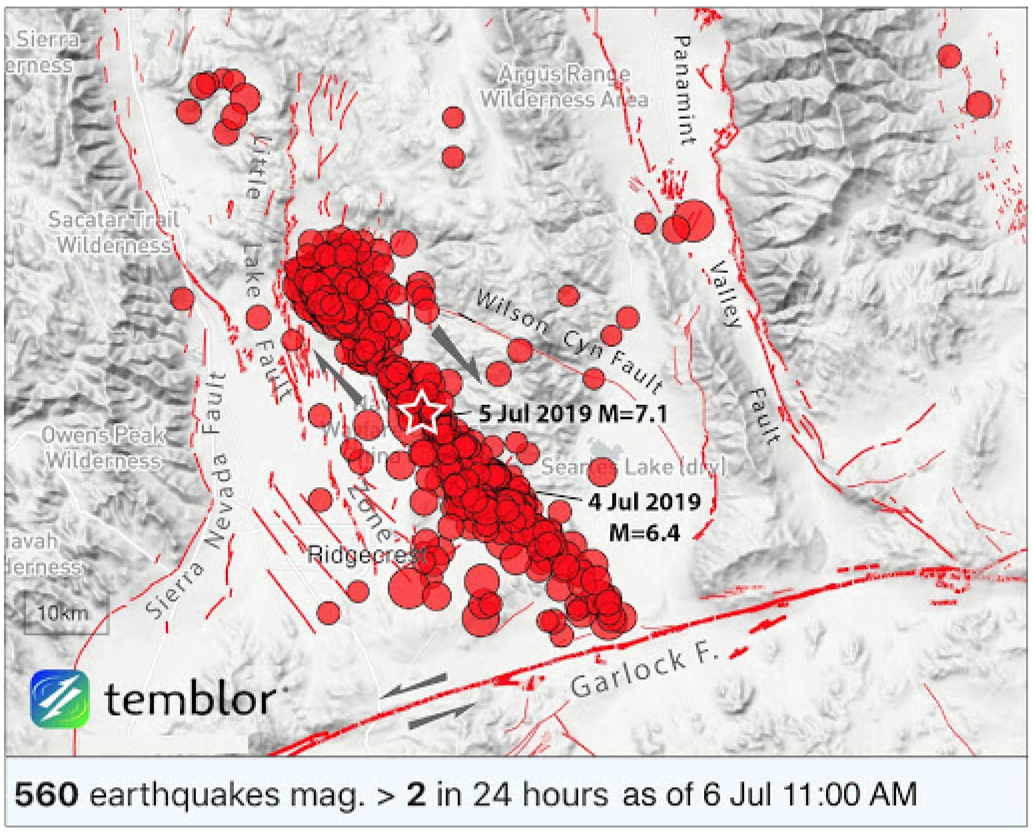
A fault out of nowhere

It is now clear that the Ridgecrest M 7.1 earthquake struck on a straight, rather simple, right-lateral (see half-arrows in the map below) rupture. That is ironic, since nothing at the ground surface had given this fault away before it fired off the quake. Some of the world's best field geologists had scoured this area for the past 50 years, because faulting is much more readily mapped in this arid, undeveloped landscape, and because of its association with geothermal activity. The latter, geothermal activity, has heated, stretched, and locally weakened the crust here. Further, this region has had a high rate of moderate shocks since seismic recording technology was enhanced in about 1980; they gave no hint of such a continuous fault.

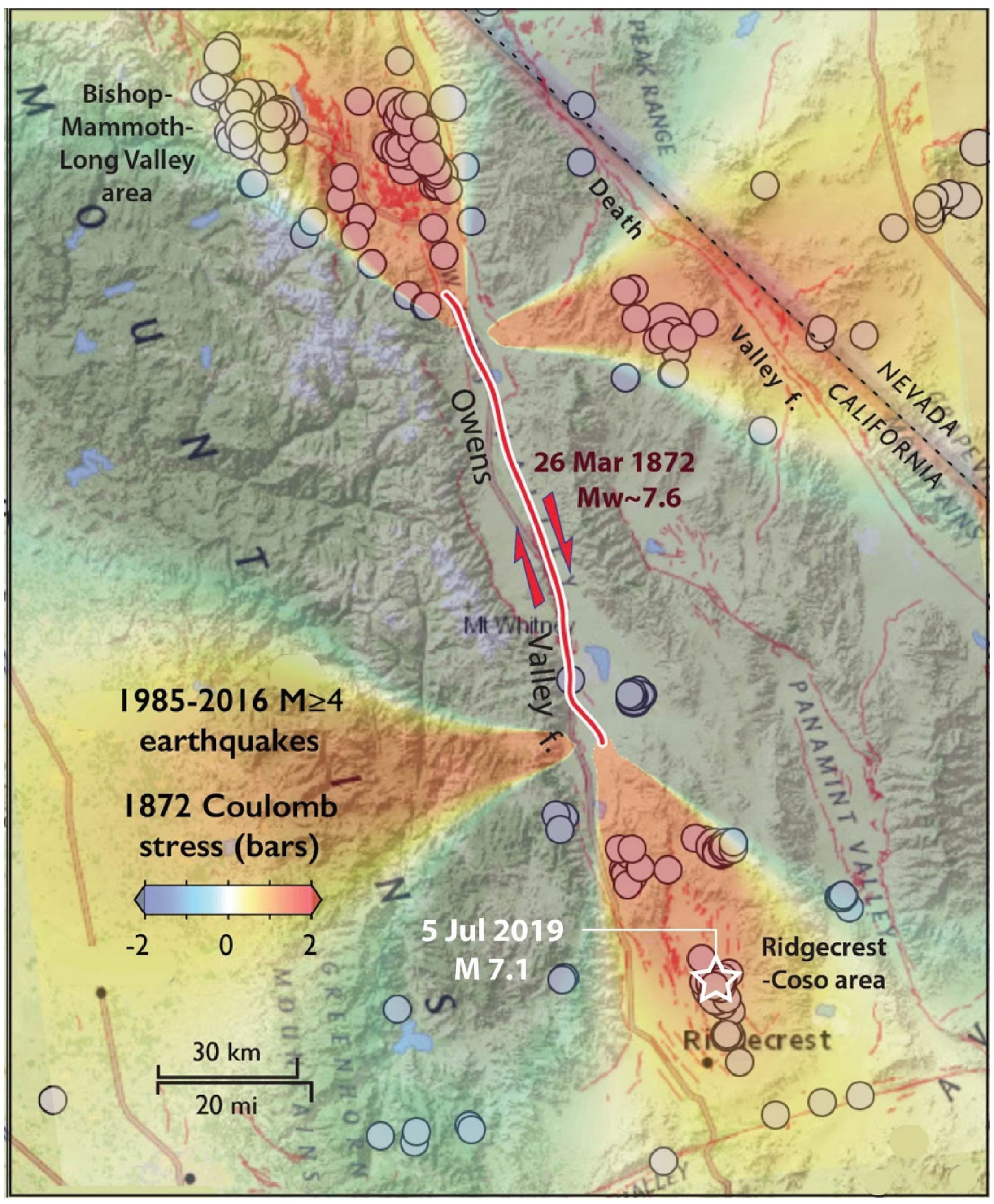


Aftershocks of the M 7.1 mainshock, as well as aftershocks of the 4 July 2019 M 6.4 mainshock, define a very straight 55-km-long trend along which up to 3 m (10 ft) of right-lateral (see grey half arrows) took place. Some of the aftershocks lie beyond the fault tips.

Chicken-or-egg riddle answered?

In a chicken-or-egg conundrum, it's never been clear whether this region is the site of continuing off-fault aftershocks of the 1872 M~7.6 Owens Valley earthquake, or whether, because the crust is heated, weak, and shocks are abundant, all of the local stress is continuously being released. If that were the case, then the 1872 shock may have been arrested just to the north because it ran out of stress (Stein, 2016).

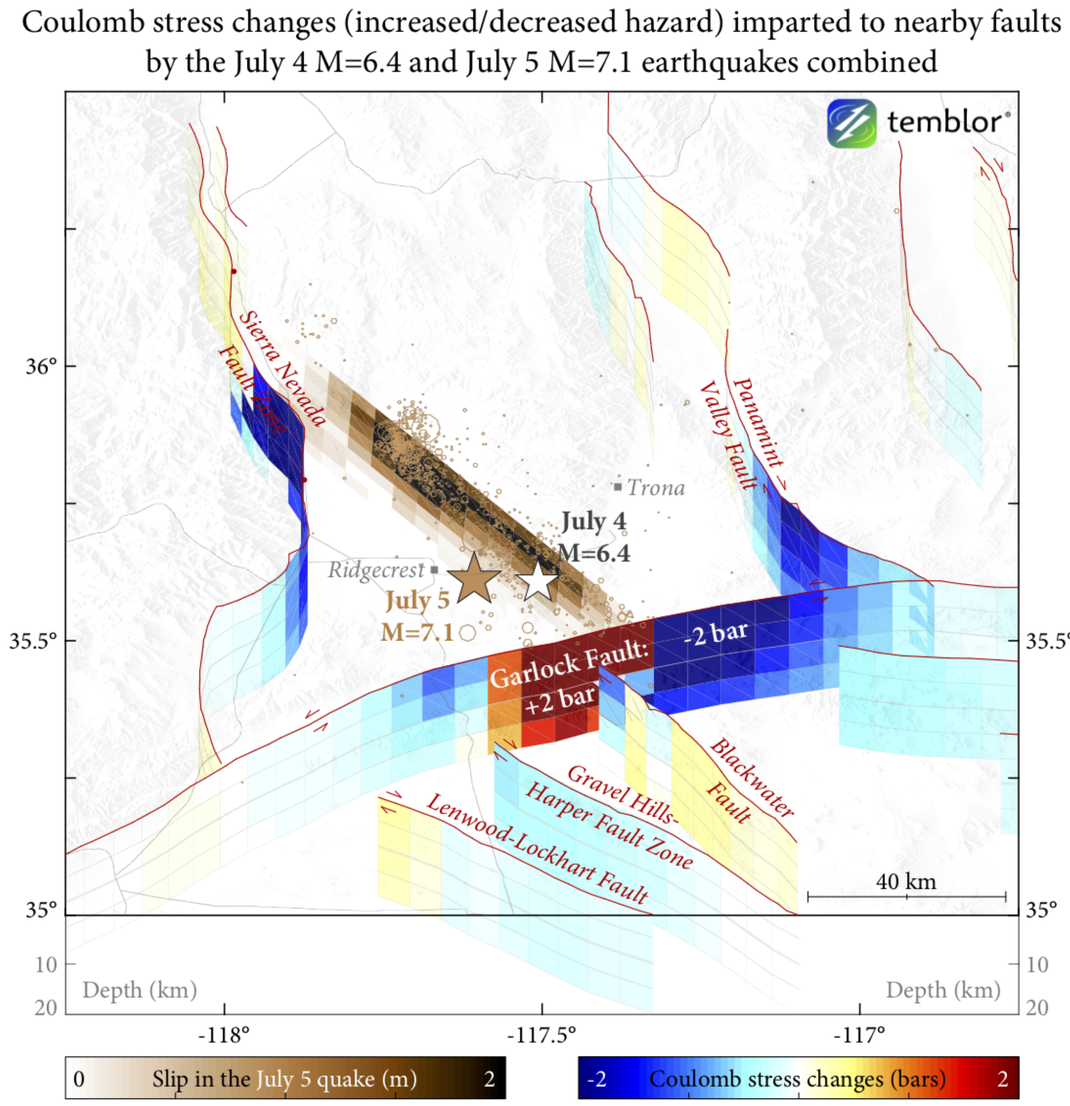
Now, the Ridgecrest M 7.1 has delivered the answer: There was plenty of accumulated stress, enough to permit a quake with 3 m (10 ft) of slip. That suggests that one can, indeed, have aftershocks 150 years after very large mainshocks, an argument we advanced in Toda and Stein (2018). This was inspired by the work of John Adams (Natural Resources Canada), John Ebel (Boston College) and Seth Stein (Northwestern University).



The M 7.1 shock struck in a lobe of calculated off-fault stress increase caused by the great 1872 M~7.6 Owens Valley shock. This area has been highly active since the seismic network became capable of recording small shocks in about 1985.

Yet another shoe to drop?

To assess which faults have now been brought closer to failure by the M=6.4 and M=7.1 earthquakes, we calculated the Coulomb stress transfer from them to nearby faults, below. The hypothesis is that earthquakes interact by the transfer of stress: they are not isolated events, but always in a kind of 'conversation' moderated by stress. Slip on faults is promoted when the faults are sheared in the same way that they naturally slip in earthquakes, and when they faults are unclamped (two sides pulled apart, making slip easier); those sites are colored red below. Faults are inhibited from failure when the imparted shear stress is opposite to the way in which they slip in earthquakes, and when the faults are clamped; those 'stress shadows' are colored blue.



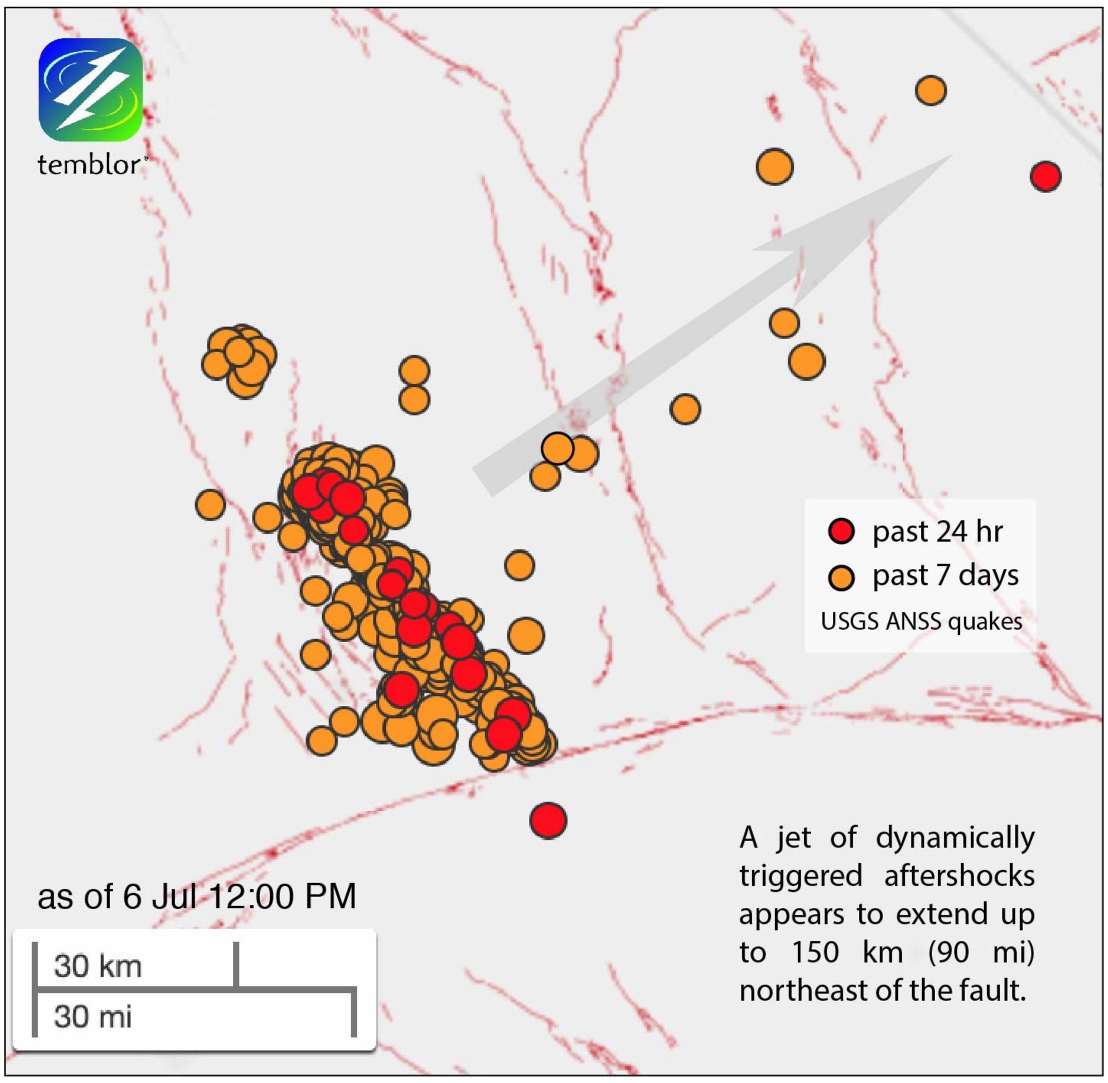
Here we calculate stress transferred to the principal mapped faults, using the USGS slip model for the 7.1 and a model based on University of Nevada Reno GPS displacements for the 6.4 (not shown here for simplicity, but included). Most of the stress change is from the 7.1: it was several times larger than the 6.4 and torqued the surrounding crust far more. This fault inventory might be woefully incomplete, of course: the 7.1 itself struck on an unmapped fault. Nevertheless, the most striking result is the >2-bar stress increase on a 30-km (20-mile) section of the Garlock Fault. An end-to-end rupture on the Garlock, if (still) possible, would be in the magnitude 7.6-7.8 range.

The biggest loser is a 30-km stretch of the Garlock Fault just south of the action that was hit by a Coulomb stress increase in excess of 2 bars. Remarkably, this section has not lit up in aftershocks. Could this stretch of the Garlock be waiting to go all in one big event? That could be, but note that Coulomb stress has been decreased on either side of the red zone, nominally making failure less likely on those sections. There might be another explanation for the silence of the red zone: that the Garlock has been rotated so far out of alignment with the tectonic stress direction that it can only slip if it is very slippery. So, despite its length (280 km, 170 mi) and the geological offsets along it, it is possible that the Garlock isn't as much of a major tectonic player these days. There have been prehistoric earthquakes on it, which would contradict this inference. In any case, the Garlock is an oddity.

Smaller but still significant stress increases are calculated for the Blackwater, Panamint Valley, and Sierra Nevada Faults. There have been a few aftershocks near these faults, so they should all be watched.

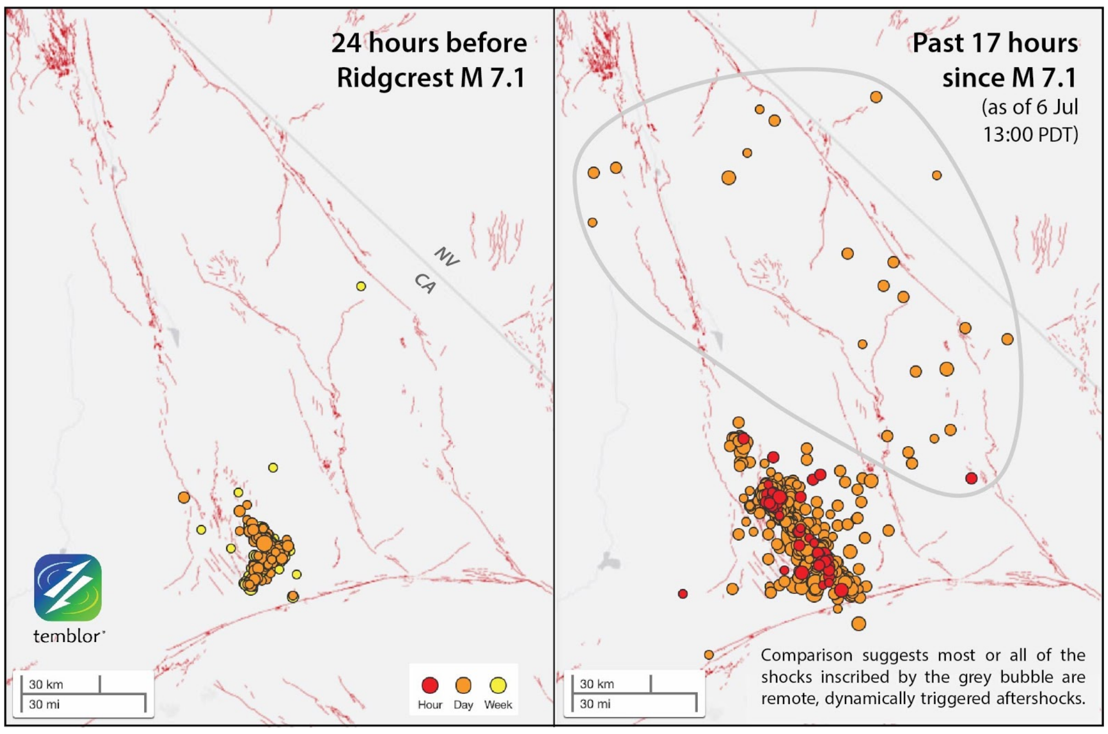
Dynamically triggered aftershocks extend to Nevada

An unmistakable jet of aftershocks can be seen extending about 150 km (90 mi) to the northeast of the mainshock. These could be 'busted locations,' when the seismic network is overwhelmed by the waves from multiple quakes and therefore unable to accurately locate events. Accordingly, this observation is preliminary. But it looks remarkably like the remote aftershocks of the 1992 M 7.3 Landers earthquake, also in the Eastern California Shear Zone, discovered by Hill et al. (1993), and seen many times since for many, but certainly not all—other large quakes.



Sparse seismicity extends out at least 150 km northeast of the main rupture. All of these events are 'aftershocks' in the sense that they struck after the mainshock, but they were not instantaneous with the arrival of the seismic wave front.

Comparing the 24 hr before the mainshock and the elapsed 17 hr afterwards (below) all but eliminates the possibility that these events are simply 'background' shocks that occur all the time. Rather, the remote shocks must be the product of the mainshock if they are indeed real quakes. But they cannot be explained by the permanent Coulomb stress changes that we previously calculated, because those stresses diminish nearly to zero about 75 km away in this case. Instead, these stresses are carried by the seismic waves, and so are transient. Somehow, they stimulate faults to slip after a delay of some hours.



In a pattern reminiscent of precedent-setting observations of David Hill and his colleagues after the 1992 M 7.3 Landers earthquake (Hill et al, 1993), which also struck in the Eastern California Shear Zone, there are widely distributed remote aftershocks that can only have been dynamically triggered, but in a delayed manner, by the seismic wavetrain.

Another mystery

We would expect the dynamic stresses carried by the seismic waves to be strongest in the direction that the fault unzipped—toward the northwest and southeast—but instead the remote shocks we see are widely distributed to the northeast. Once again, a quake has broken all our rules.

Parting shot

After a M 4.0 was followed 30 min later by a M 6.4, and the M 6.4 was followed 34 hr later by a M 7.1, we should all ask ourselves if we are ready for whatever this earthquake sequence—or the next one—may bring. That means putting a whistle on your keychain. It means having an earthquake emergency kit in your home, car, and place of work (http://temblor.net/earthquake-insights/earthquake-emergency-kit-for-a-gift-220/). It means having a communication plan, and a solar charger and cell phone battery in your kit. It means making sure your home and its contents are as seismically resilient as possible, and asking whether you could deal with the repair cost and dislocation if it is not. Empower yourself in the face of a trembling earth.

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References

Hauksson, E., & Unruh, J. (2007). Regional tectonics of the Coso geothermal area along the intracontinental plate boundary in central eastern California: Three-dimensional Vp and Vp/Vs models, spatial-temporal seismicity patterns, and seismogenic deformation. *Journal of Geophysical Research*, *112*(B6).

Hill, David P, P. A. Reasenberg, A. Michael, W. J. Arabaz, G. Beroza, D. Brumbaugh, J. N. Brune, R. Castro, S. Davis, D. dePolo, W. L. Ellsworth, J. Gomberg, S. Harmsen, L. House, S. M. Jackson, M. J. S. Johnston, L. Jones, R. Keller, S. Malone, L. Munguia, S. Nava, J. C. Pechmann, A. Sanford, R. W. Simpson, R. B. Smith, M. Stark, M. Stickney, A. Vidal, S. Walter, V. Wong, J. Zollweg (1993), Seismicity Remotely Triggered by the Magnitude 7.3 Landers, California, Earthquake, *Science, 260*, 1617-1623, DOI: 10.1126/science.260.5114.1617

McAuliffe, L. J., J. F. Dolan, E. Kirby, C. Rollins, B. Haravitch, S. Alm, and T. M. Rittenour (2013), Paleoseismology of the southern Panamint Valley fault: Implications for regional earthquake occurrence and seismic hazard in southern California, *J. Geophys. Res., 118*, 5126–5146, doi:10.1002/jgrb.50359.

Stein, Ross S. (2016), Eastern California's intense seismic and geothermal activity: Chicken or Egg? Temblor, http://temblor.net/earthquake-insights/eastern-california-intense-seismic-and-geothermal-activity-594/

Shinji Toda and Ross S. Stein (2018), Why Aftershock Duration Matters for Probabilistic Seismic Hazard Assessment, *Bull. Seismol. Soc. Amer., 108*, 1414-1426, https://doi.org/10.1785/0120170270

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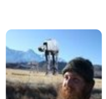

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David Jacobson • 12 days ago

A question I have relates to bringing up this event as an aftershock of the 1872 earthquake. If that's the case, then when are earthquakes in areas of previous large events not aftershocks? In this instance, it's nearly 150 years post Owens Valley earthquake.

1 • Reply • Share ›

Ross Stein Mod ➦ David Jacobson • 12 days ago • edited

It is very difficult to be certain if these are late aftershocks, since we don't know what the seismicity was before the 1872 quake, and we cannot observe a rate decay today. But there are other cases where it is clear that more than 100 years after a large quake, aftershocks continue, because their frequency decays with inverse time, and their rate has been tracked since the mainshock struck. Perhaps the most challenging and important cases is the 1811-1812 New Madrid quakes, an area of high seismicity today. These may well be aftershocks, too. The duration of an aftershock sequence appears to be inversely proportional to the stressing rate on the fault, and so areas with very low stressing rates (and so low slip rates) seem to have the longest aftershock durations.

2 ^ | v • Reply • Share ›

CHeden ➦ Ross Stein • 12 days ago • edited

IMHO, the "loose" definition of an aftershock is the release of residual stress that's either native or transferred. At some point in time after the primary rupture (maybe as long as a couple of years as with Loma Prieta), native/tectonic stress will resume accumulating... eventually leading to a future rupture.

It's when this "new" stress resumes accumulating that the clock starts ticking leading up to the next earthquake in the sequence...and any quake after this point in time I would not characterize as an "aftershock". If stress does get transferred to an adjacent fault that "accelerates" it's "normal" rate of failure, then all that changes is the timeline, since a potential earthquake was already in the making and just got an extra-push from it's big brother.

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Kareem J. Lanier • 11 days ago • edited

Hey Dr. Ross, I've followed you since the Bay Area was reminded about their seismicity with Loma Prieta in 1989 and the 2 foreshocks leading up to it. Now that I live up in the Sacramento area, I feel like I miss all the activity. Lol. So, it's been awhile. One of the things that's intriguing to me is how different the activity in the Bay Area is versus the activity down south. Seems like socal quakes tend to have a much more robust quake sequence than Bay Area - that's just my loose interpretation.

In any case, this Ridgecrest event (M6.9) does appear to be a on a NNW trending fault which is vastly different from the fault responsible for the M6.4. I've seen some photos of what appears to be left-lateral offsets from cracks in a road but I assume those are from the M6.4 event. Are there any new photos of ground rupture from the later M6.9 event? I've heard the rupture from that is 'right-lateral'? Also where can I get more on the latest articles or writeups regarding this particular sequence?

^ | v • Reply • Share ›

Ross Stein Mod ➦ Kareem J. Lanier • 8 days ago

We have seen some photos, but the best guide right now is the interferogram in our most recent article.

1 ^ | v • Reply • Share ›

Kareem J. Lanier ➦ Ross Stein • 8 days ago

Thanks!!

^ | v • Reply • Share ›

ekamc1986 • 11 days ago

I admire all the work you do. Thanks for this effort. I do take small issue in the idea that this event came out of nowhere, or that geologists didn't know there were faults here. There are a number of faults shown on recent maps in the CGS publications, including what is called Little Lake Fault Zone, and even a fault shown on the old Trona 1x2 sheet. On the CGS interactive map, these faults individually have strikes that are more northerly than the main 7.1 event; the overall trend is NNW for the zone. One hypothesis is that the 7.1 event somehow is linking or connecting through along the LLFZ. This would be consistent with various fault structural evolution models, based on various mechanical models, a la Pollard, Martel, etc., analog models, that typically show en echelon fractures and small faults developing above a later through-going fault fractures and small faults developing above a later through-going fault, and some field based analyses that motivated some geometric and kinematic models.

What does seem more obscure is the NNE striking fault associated with the M 6.4 event.

One other point - and I am not a geomorphologist, but faults are not necessarily easier to find if there is little vegetation. There are hints of fault traces on Google Earth imagery, and these arid regions can actually be quite challenging as these surfaces can be quite active - wind, a few surface floods, etc., a few 100 yrs, and most evidence for a strike slip fault trace could become quite hard to see.

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Ross Stein Mod → ekamc1986 • 8 days ago

All good points. To its credit, in 2014, the USGS produced a scenario M 6.9 event on the Little Lake Fault that is not entirely different than the Ridgecrest event. But the larger point is that we have a long history of missing the faults on which M≤7.1 quakes can strike (Loma Prieta, Northridge, Darfield NZ), so hazard assessments that depend on a complete fault inventory will never be right. The second point is that we have other Calif faults that appear to be composed of short discontinuous segments, such as the Newport-Ingewood Fault Zone that cuts through the LA basin, and we have long argued about whether they could rupture all at once. I think Ridgecrest answered that question in the affirmative.

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David Alao • 11 days ago

If the behavioral patterns are breaking the rules, there is a wider margin of errors predicting the sequence of events. I like the advice asking the populace to stock survival kits at home in the car and the office.

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Ross Stein Mod → David Alao • 8 days ago

Agreed. That's why we do not use the word, 'prediction.' It is something we cannot do. The 1989 M 7.1 Loma Prieta, 1994 M 6.7 Northridge, and 2011 M 7.0 Darfield, NZ, quakes all struck on heretofore unknown faults, despite extensive field mapping. Humbling.

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felixlopezmail@gmail.com • 12 days ago

Ross - I work in the energy industry. The industry is observing any mass land shifts that may impact the extensive network of pipelines coming from Texas (Permian Basin) delivering petroleum products, natural gas and other related products to California. Does the Temblor team have any anecdotal or empirical data on land shifts or other related. I can clarify if needed. Thank you.

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Ross Stein Mod → felixlopezmail@gmail.com • 12 days ago

GPS ground displacements and InSAR imagery (Interferometric Synthetic Aperture Radar from satellites) should soon be available, and this data will tell us what deformation accompanied and followed the quake. We will report on it as soon as we learn more.

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CHeden → Ross Stein • 11 days ago • edited

Just found this recent release from NGL showing the SoCal GPS/Coseismic Displacement data following the 7.1Mw quake. It appears most of the western half of SoCal down to the Mexican border moved...at least a little bit.

http://geodesy.unr.edu/news...

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Bob Anderson • 12 days ago

Can the 1872 Owens Valley earthquake, The Searles Valley earthquakes, the Landers and Hector Mine earthquakes and one or several of the

Imperial County earthquakes be related and possibly be a part of opening or extension of the Gulf of California?

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Ross Stein Mod → Bob Anderson • 12 days ago

They are all related to the existence of the Eastern California Shear Zone, which is younger than the San Andreas system. The San Andreas goes through the Big Bend bordering the southern Mojave, and is misaligned with the plate motion. The Shear Zone appears to have formed as a result of that misalignment.

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Craig Langbein • 12 days ago

The locations of many of the events coincide with Holocene faults shown on the California Fault Activity Map (Jennings & Bryant, 2010), including the SW-NE trending aftershocks in the southern third of the cluster

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