South Napa earthquake linked to summer groundwater dip

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Surface ruptures from the August 2014 South Napa earthquake run through a vineyard near Buhman Road, Napa Valley, California. Credit: Dan Ponti, US Geological Survey

A summertime expansion in the Earth's crust caused by changes in groundwater may have triggered the magnitude-6.0 earthquake in California's wine country in 2014, according to a new study.

The August 24, 2014 South Napa quake was the largest earthquake to shake the San Francisco Bay Area since the magnitude-6.9 Loma Prieta quake in 1989. It was also the first earthquake in the region since 1906 to break through to the surface, leaving buckled asphalt and cracked soil in vineyards along the length of the fault.

The earthquake originated 11.1 kilometers (6.7 miles) under the San Pablo Bay marshes along the West Napa Fault. Falling bricks, debris and household objects killed two people and injured close to 300, and the earthquake caused roughly half a billion dollars of damage.

The Earth's surface is a collage of thin, rigid plates floating on a hot, liquid interior. Friction prevents the plates from moving smoothly past each other and stress builds up in the rocks as the plates pull and push on each other. Earthquakes occur when pieces of the Earth's crust slide past each other to release this stress.

In the new study in the *Journal of Geophysical Research*: Solid Earth, a journal of the American Geophysical Union researchers report the discovery of an expansion occurring in Earth's crust every summer at the site of the South Napa earthquake, adding to the stress on the fault. Their analysis suggests seasonally receding groundwater under the Napa and Sonoma valleys, which flank the fault, causes the summertime expansion.

The study's authors believe the added seasonal stress could have been the final straw that caused the fault to fail in 2014.

"You have an overall, long-term accumulation of stress in the Earth, that happens from standard plate tectonics forces. Then you have a seasonal component," said Meredith Kraner, a graduate student at the University of Nevada, Reno, and lead author of the new study. "We think that seasonal component may have pushed the fault slightly more towards

failure."

Plate Boundary Observatory GPS station P199 overlooks the Sonoma Valley, California. Data from the station demonstrated contraction in the valley during the summer, which contributes to seasonal stress on the fault that ruptured in the magnitude 6.0 South Napa Earthquake in 2014. Credit: UNAVCO

"Why did [the earthquake] happen in 2014 versus any other year? We think it just reached its breaking point," Kraner said.

Previous studies of earthquake patterns in California have also observed

seasonal trends, with earthquakes occurring more frequently in the summer months. The new study ties this seasonal effect to a specific earthquake and delves deeper into how it may have contributed to the timing of the 2014 earthquake.

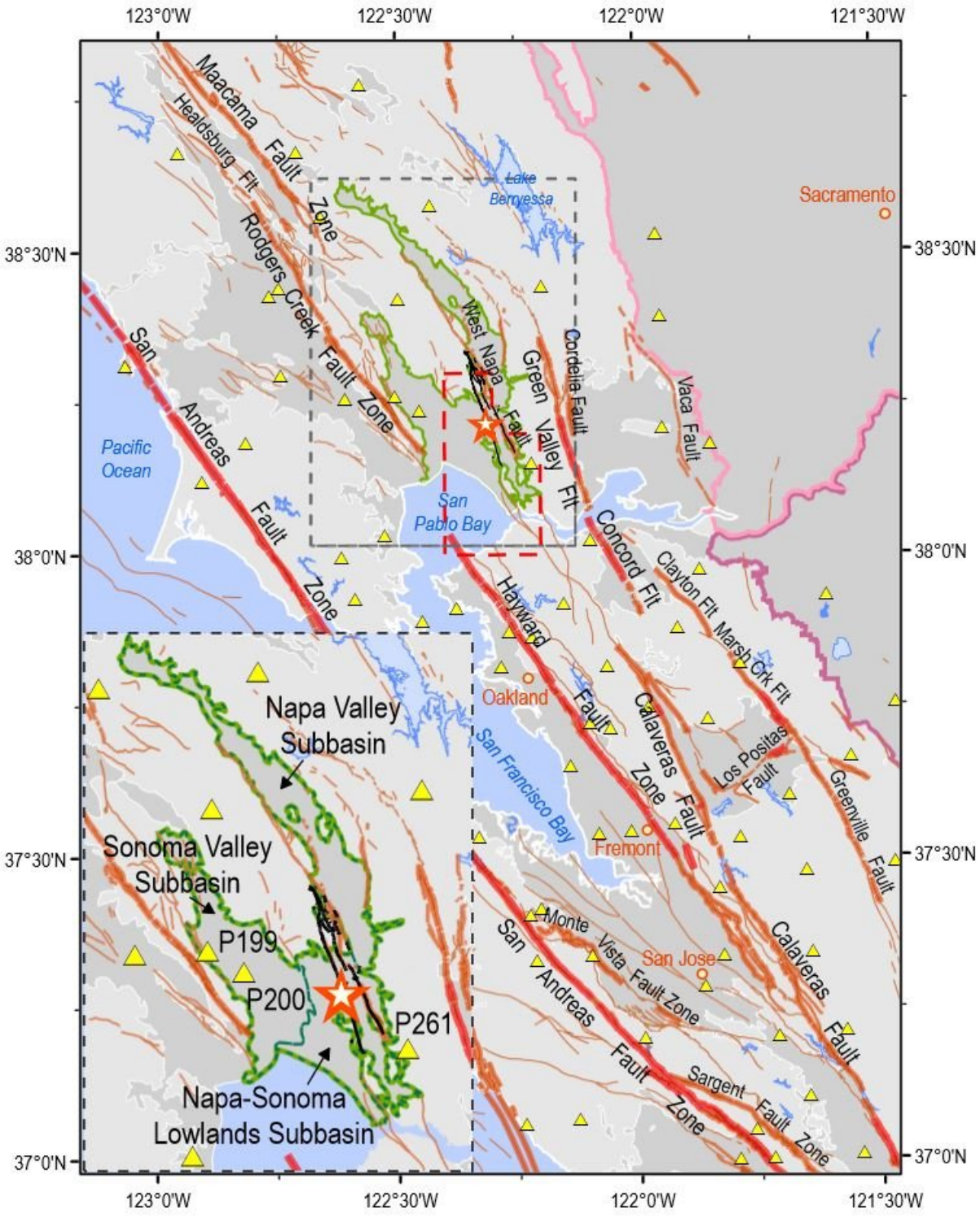
Studies like this one could improve earthquake forecasting models by incorporating localized, seasonal sources of stress on faults, which could be important earthquake triggers, Kraner said. Seasonal influences vary between faulting systems, but current models rely only on the overall, long-term movements of the Earth's crust.

"Although this study promises to improve forecasting models by encouraging agencies to include time-dependent information, we just can't predict earthquakes," Kraner said. "This is promising, but we still can't predict anything."

Summer stress

The new study finds Earth spreads horizontally, roughly east-west, during the summer in the area where the fault ruptured in 2014. This spreading reaches a peak of 3 millimeters (0.12 inches) in late August to early September.

In the winter, the crust contracts to the same degree, reaching a maximum contraction in late January to early February. This seasonal pattern of expansion and contraction happened annually in the eight years before the South Napa earthquake.



A star marks the epicenter of the August 2014 South Napa earthquake and black traces the West Napa Fault. Contraction in the Sonoma and Napa Valley

groundwater subbasins, outlined in green, during the summer pulls on the Earth's crust between the valleys, contributing to stress on the fault and potentially triggering the 2014 earthquake, according to a new study. Yellow triangles mark the locations of GPS stations used to measure motions in the Earth's crust. Credit: AGU *Journal of Geophysical Research*: Solid Earth

Kraner observed these seasonal motions in the Earth using an array of GPS stations throughout the western United States. Each station reports its location down to the millimeter.

"We found that the expansion happens every summer, and we believe that it causes an overall release of clamping pressure on the fault, which we believe makes the fault more likely to slip during the summer months," Kraner said.

Kraner and her colleagues believe seasonal fluctuations in groundwater, whether from pumping or other changes, are likely the source of the seasonal expansion and contraction. The weight of groundwater flexes the Earth's crust, and changes in groundwater have been associated with earthquakes around the world. For example, the unloading of water weight as the Sierra Nevada snowpack melts each spring has been connected to increased frequency of earthquakes in the summer in California.

The new study shows the observed seasonal expansion over the fault is consistent with the waxing and waning of water under Napa and Sonoma, two long valleys that run parallel to each other, divided by the Mayacamas Mountains. Groundwater basins within the valleys supply water to the region's famous wineries. The West Napa Fault runs between the valleys on the eastern edge of the mountains.

As water levels under the valleys fall during the summer, the ground over the valleys sinks and contracts. Satellite data shows the land sinking in the Napa and Sonoma valleys in the summer, consistent with shrinking groundwater volume. Eastern and western GPS stations within Sonoma Valley also move closer together in summer, showing a contraction over the groundwater basin, which would be expected as groundwater diminishes.

This contraction above the groundwater basins pulls on the mountainous land between the valleys, causing the land between the valleys to stretch. This is the seasonal expansion Kraner and her colleagues observed using GPS that they believe adds stress to the fault.

The researchers ruled out other factors, like changes in air temperatures, the Sierra Nevada snowpack and the extended 2011-2017 California drought, as the cause of the local changes.

"We think it's more of a localized effect, something related to the groundwater system. We don't know if it is groundwater pumping specifically, or something related to how the natural aquifer system works, or a combination," Kraner said.

More information: Meredith L. Kraner et al. Seasonal non-tectonic loading inferred from cGPS as a potential trigger for the M6.0 South Napa Earthquake, *Journal of Geophysical Research: Solid Earth* (2018). DOI: 10.1029/2017JB015420