Sun and moon trigger deep tremors on San Andreas Fault

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The faint tug of the sun and moon on the San Andreas Fault stimulates tremors deep underground, suggesting that the rock 15 miles below is lubricated with highly pressurized water that allows the rock to slip with little effort, according to a new study by University of California, Berkeley, seismologists.

"Tremors seem to be extremely sensitive to minute stress changes," said Roland Bürgmann, UC Berkeley professor of earth and planetary science. "Seismic waves from the other side of the planet triggered tremors on the Cascadia subduction zone off the coast of Washington state after the Sumatra earthquake last year, while the Denali earthquake in 2002 triggered tremors on a number of faults in California. Now we also see that tides - the daily lunar and solar tides - very strongly modulate tremors."

In a paper appearing in the Dec. 24 issue of the journal Nature, UC Berkeley graduate student Amanda M. Thomas, seismologist Robert Nadeau of the Berkeley Seismological Laboratory and Bürgmann argue that this extreme sensitivity to stress - and specifically to shearing stress along the fault - means that the water deep underground is under extreme pressure.

"The big finding is that there is very high fluid pressure down there, that is, lithostatic pressure, which means pressure equivalent to the load of all rock above it, 15 to 30 kilometers (10 to 20 miles) of rock," Nadeau said. "Water under very high pressure essentially lubricates the rock,

making the fault very weak."

Though tides raised in the Earth by the sun and moon are not known to trigger earthquakes directly, they can trigger swarms of deep tremors, which could increase the likelihood of quakes on the fault above the tremor zone, the researchers say. At other fault zones, such as at Cascadia, swarms of tremors in the ductile zone deep underground correlate with slip at depth as well as increased stress on the shallower "seismogenic zone," where earthquakes are generated. The situation on the San Andreas Fault is not so clear, however.

"These tremors represent slip along the fault 25 kilometers (15 miles) underground, and this slip should push the fault zone above in a similar pattern," Bürgmann said. "But it seems like it must be very subtle, because we actually don't see a tidal signal in regular earthquakes. Even though the earthquake zone also sees the tidal stress and also feels the added periodic behavior of the tremor below, they don't seem to be very bothered."

Nevertheless, said Nadeau, "It is certainly in the realm of reasonable conjecture that tremors are stressing the fault zone above it. The deep San Andreas Fault is moving faster when tremors are more active, presumably stressing the seismogenic zone, loading the fault a little bit faster. And that may have a relationship to stimulating earthquake activity."

Seismologists were surprised when tremors were first discovered more than seven years ago, since the rock at that depth - for the San Andreas Fault, between 15 and 30 kilometers (10 to 20 miles) underground - is not brittle and subject to fracture, but deformable, like peanut butter. They called them non-volcanic tremors to distinguish them from tremors caused by fluid - water or magma - fracturing and flowing through rock under volcanoes. It was not clear, however, what caused the non-volcanic

tremors, which are on the order of a magnitude 1 earthquake.

To learn more about the source of these tremors, UC Berkeley seismologists began looking for tremors five years ago in seismic recordings from the Parkfield segment of the San Andreas Fault obtained from sensitive bore-hole seismometers placed underground as part of the UC Berkeley's High-Resolution Seismic Network. Using eight years of tremor data, Thomas, Bürgmann and Nadeau correlated tremor activity with the effects of the sun and moon on the crust and with the effects of ocean tides, which are driven by the moon.

They found the strongest effect when the pull on the Earth from the sun and moon sheared the fault in the direction it normally breaks. Because the San Andreas Fault is a right-lateral strike-slip fault, the west side of the fault tends to break north-northwestward, dragging Los Angeles closer to San Francisco.

"When shear stress on a plane parallel to the San Andreas Fault most encourages slipping in its normal slip direction is when we see the maximum tremor rate," Bürgmann said. "The stress is many, many orders of magnitude less than the pressure down there, which was really, really surprising. You essentially could push it with your hand and it would move."

In fact, the shear stress from the sun, moon and ocean tides amount to around 100 Pascals, or one-thousandth atmospheric pressure, whereas the pressure 25 kilometers underground is on the order of 600 megaPascals, or 6 million times greater.

Nadeau and colleagues reported earlier this year that earthquakes in 2003 and 2004 near the Parkfield segment of the San Andreas Fault increased both tremor activity and stress on the fault itself.

In addition, Nadeau noted, other scientists have shown small tidal effects on tremors in the Cascadia subduction zone, with increased amplitude during certain periods, though they were unable to distinguish between tugs along the fault and tugs across, or normal to, the fault.

"We were really able to tighten the nuts down on whether it is a normal-fault stress change or an along-fault stress change that is stimulating the tremor," he said. The fact that tremors are triggered by along-fault shear stress "means that fluids are probably the explanation."

It may be that tremors only occur on faults where fluid is trapped deep underground with no cracks or fractures allowing it to squirt away, Nadeau added. That may explain why tremors are not observed on other faults, despite intense searching.

"There is still all lot to learn about tremor and earthquakes in fault zones," he said. "The fact that we find tremors adjacent to a locked fault, like the one at Parkfield, makes you think there are some more important relationships going on here, and we need to study it more."

Provided by University of California - Berkeley

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