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Human-induced uplift of the Sierra Nevada Mountains and seismicity modulation on the San Andreas Fault

Colin Amos (1), Pascal Audet (2), William C. Hammond (3), Roland Burgmann (4,5), Ingrid A. Johanson (4), and Geoffrey Blewitt (3)

(1) Department of Geology, Western Washington University, Bellingham, WA 98225, USA, (2) Department of Earth Sciences, University of Ottawa, Ottawa, ON, K1N 6N5, Canada, (3) Nevada Bureau of Mines & Geology, University of Nevada, Reno, NV 89557, USA (gblewitt@unr.edu), (4) Berkeley Seismological Laboratory, University of California, Berkeley, CA 97720 USA, (5) Department of Earth & Planetary Science, University of California, Berkeley, CA 97720, USA

We investigate the cause of geodetically observed mountain uplift in the Sierra Nevada, western US. In the process, we reveal a possible human-induced mechanism that may be driving Sierra Nevada uplift, and may also be pushing the San Andreas Fault closer to failure. An initial study of the Sierra Nevada [Hammond et al., Geology, 40, 2012] exploited the complementary strengths of point positions from GPS and blanket coverage measurements from InSAR, to show that contemporary vertical motion of the Sierra Nevada is between 1 – 2 mm/yr relative to the comparatively stable Great Basin to the east. One possible interpretation of this is that the most modern episode of tectonic uplift is still active in the Sierra Nevada. However, we now discover that GPS stations surrounding the southern San Joaquin Valley in California show a pattern of uplift concentrated not only in the Sierra Nevada to the east, but more broadly along the basin margins, including the adjacent central Coast Range to the west. Peak vertical velocities reach values up to 1 – 3 mm/yr. This suggests the San Joaquin Valley plays a key role in the uplift of the Sierra Nevada to the east, with possible implications for the San Andreas Fault to the west.

Anthropogenic groundwater depletion in the southern San Joaquin Valley has been massive and sustained, therefore hydrological loading variation might explain contemporary uplift. To test this, we apply a simple elastic model that uses a line load centered along the valley axis, a range of elastic parameters, and published estimates of the integrated rate of mass loss due to groundwater removal over the last decade. Predicted uplift centered along the valley axis matches well with patterns of GPS motion, with the upward vertical rates decaying away from the valley margins. Observed seasonal variability in the vertical GPS positions lends support for this model, showing peak uplift for stations surrounding the valley during the dry summer and fall months. On the other hand, stations in the San Joaquin Valley show larger seasonal uplift accompanying aquifer recharge during winter months.

To the east, we note that the signal of vertical flexural uplift from groundwater unloading overlaps with the possible signal of modest, contemporary uplift of the southern Sierra Nevada from tectonic and/or mantle flow derived forces. Thus at least some of the signal previously interpreted as tectonic uplift may be a consequence of massive human-induced groundwater changes in the adjacent San Joaquin Valley. To the west, we note that uplift in the Coast Range tends to unclamp the San Andreas Fault, by reducing the effective normal stress given its orientation parallel to the valley axis. Seasonal unloading due to groundwater removal therefore may provide a viable mechanism to explain previously observed peaks in seismicity during dry months along this portion of the fault, and perhaps pushes the San Andreas fault closer to failure.