USGS science for a changing world

California Volcano Observatory

Long Valley Caldera 2003 through 2014: Overview of Low Level Unrest in the Past Decade

By

Stuart Wilkinson, David P. Hill, John O. Langbein, Mike Lisowski, and Margaret Mangan

2014

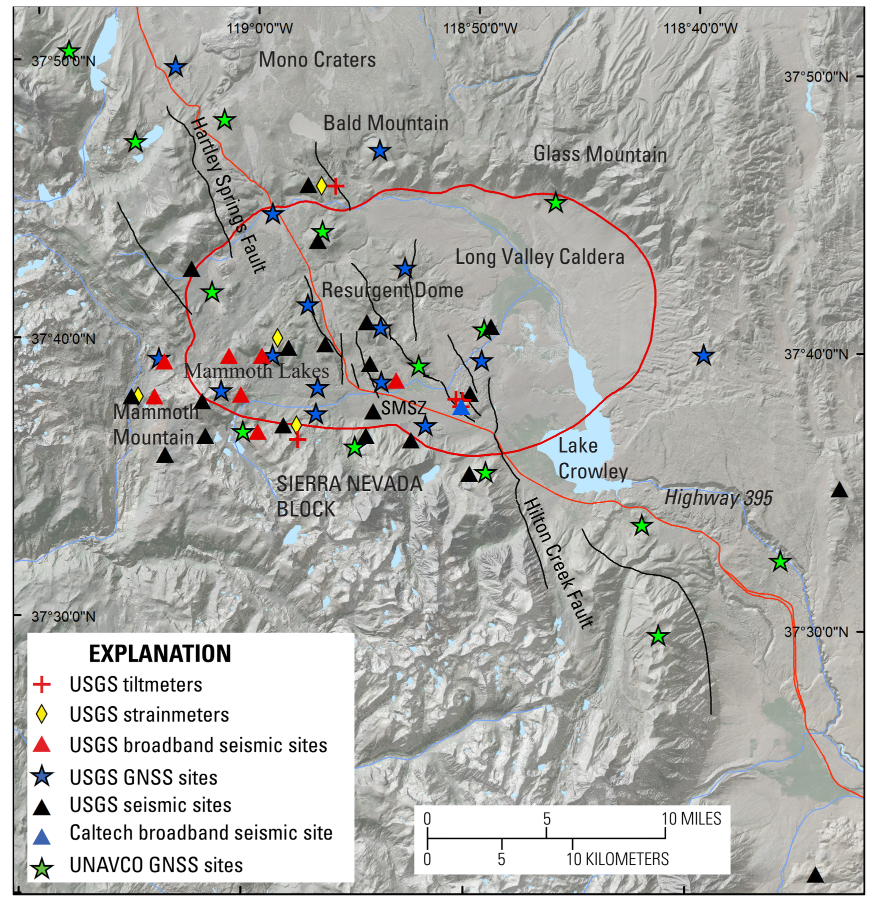
Long Valley Caldera—California's Restless Giant

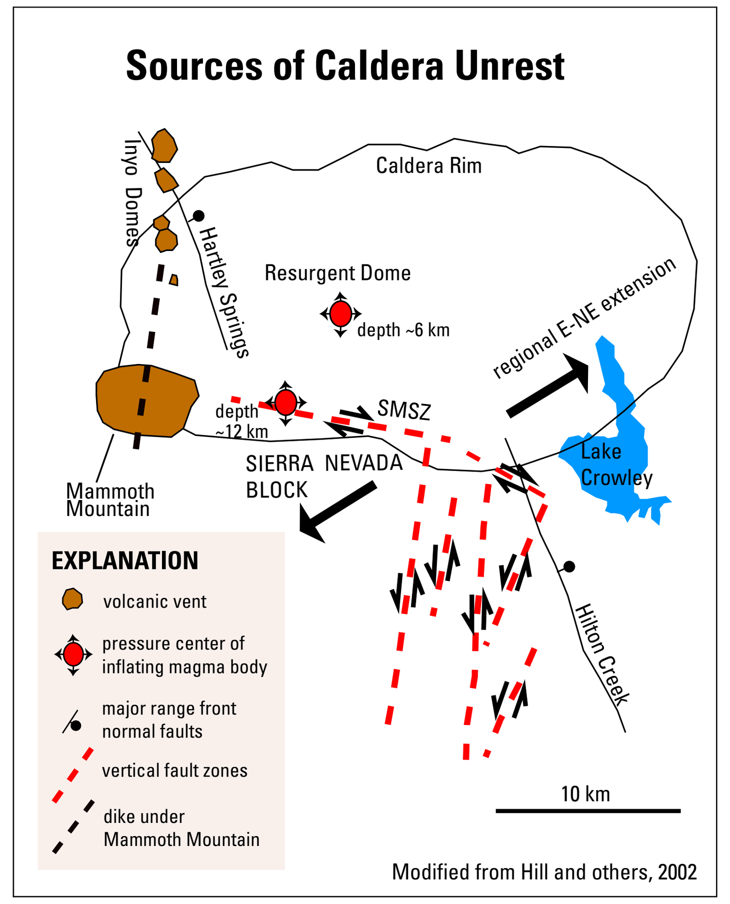
View of Long Valley Caldera (LVC) looking eastward from Mammoth Mountain.

LVC is located in California along the eastern escarpment of the Sierra Nevada Range. The caldera formed about 760,000 years ago as the eruption of 600 km^3 of rhyolite magma (Bishop Tuff) resulted in collapse of the partially evacuated magma chamber. Resurgent doming in the central part of the caldera occurred shortly afterwards, and the most recent eruptions inside the caldera occurred about 50,000 years ago. The caldera remains thermally active, with many hot springs and fumaroles, and has had significant deformation and seismicity since at least 1978. Periods of intense unrest in the 1980s to early 2000s are well documented in the literature (Hill and others, 2002; Ewert and others, 2010). In this poster, we extend the timeline forward, documenting seismicity and deformation over the past decade.

The U.S. Geological Survey (USGS) California Volcano Observatory monitors Long Valley Caldera and vicinity with continuous Global Navigation Satellite System (GNSS), seismometers, tiltmeters, and strainmeters.

High precision deformation measurements evolved from labor intensive leveling and 2-color Electronic Distance Measurement (EDM) techniques to automated measurements from continually operating GNSS receivers. While both the older and newer technologies have the same precision, the new instruments allow for real-time recording at a 1-second interval of deformation. The LVC seismic network consists of 30 telemetered sites, including 8 broadband stations. The tiltmeter network includes 2 borehole tiltmeters, and one long baseline tiltmeter capable of resolving changes of 0.1 microradian over a week and 1.0 microradian over a year. The strain network consists of 3 dilatometers capable of detecting 0.02 ppm changes over days and 0.01 ppm over hours.

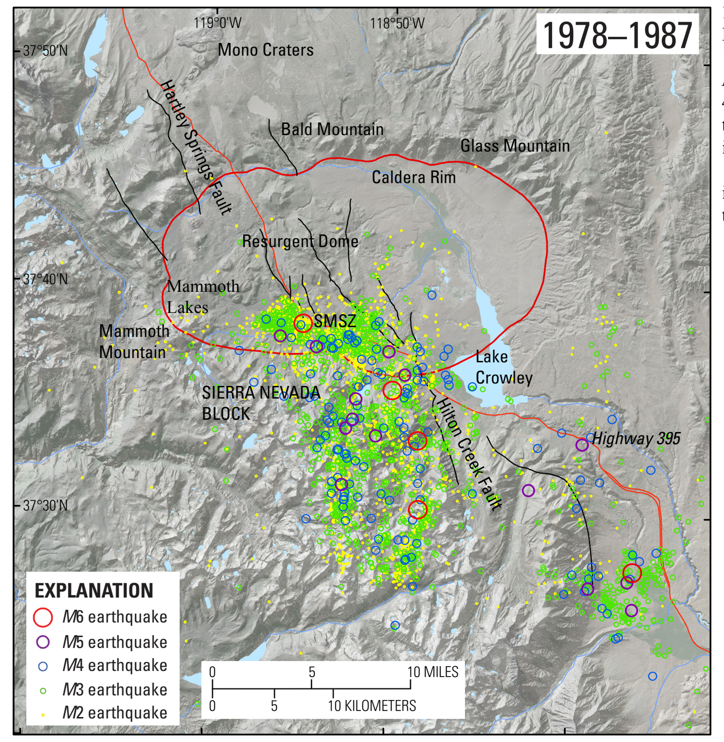




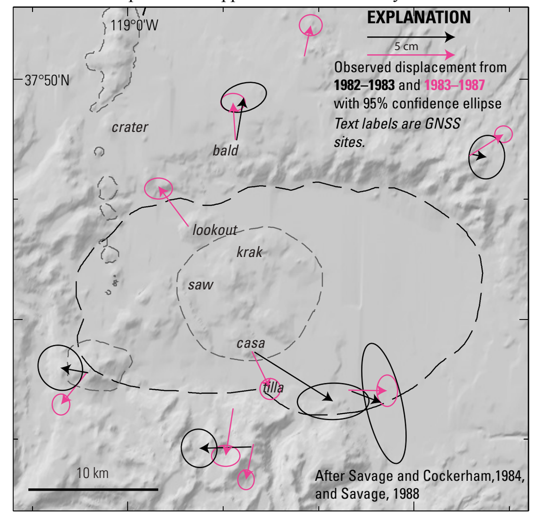
Locations of inferred sources contributing to the 1978–1999 unrest in Long Valley Caldera and vicinity.

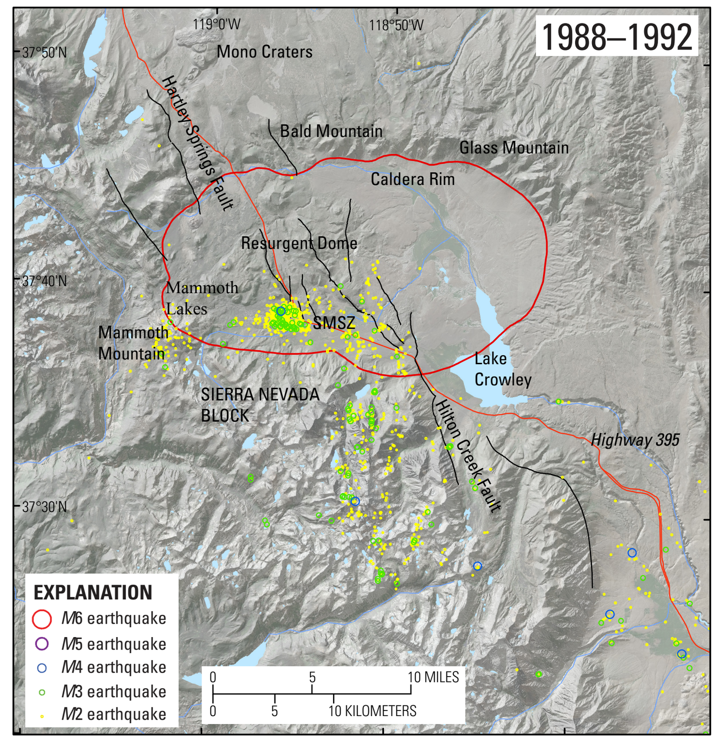
Red circles indicate centers of inflating magma bodies. The dashed black line indicates a dike intruded beneath Mammoth Mountain in 1989. Thick red dashed lines indicate near-vertical fault zones. Double-barbed arrows indicate sense of slip across fault systems. Large arrows indicate regional east-northeast extension. Major range-front normal fault systems are indicated by solid lines with ball on the down-dropped block. SMSZ: south moat seismic zone.

Unrest in Long Valley Caldera and vicinity from 1978 to 2003

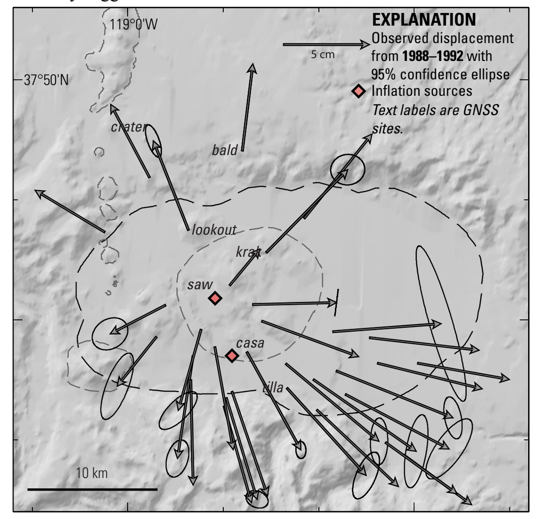


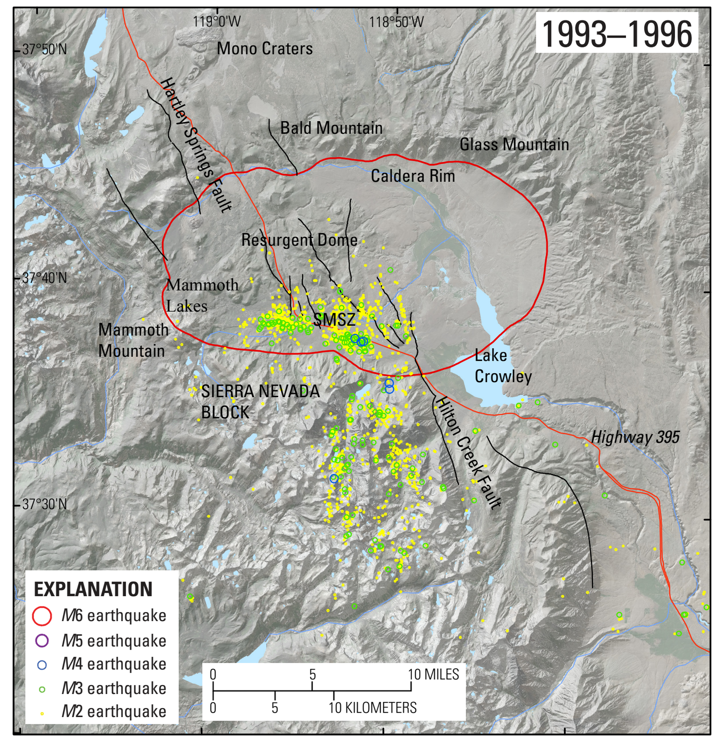
1978–1983: Dramatic seismicity and uplift, then calm.
Intermittent *M*3–*M*4 earthquakes in the South Moat Seismic Zone (SMSZ) in 1978 were followed by an intense seismic swarm in May 1980 that included 4 *M*>6 earthquakes in the SMSZ and Sierra Block. Focal mechanisms for 2 of the 4 earthquakes suggest they were caused by magma or hydrothermal fluid injection. The swarm coincided with 25 cm of resurgent dome uplift. New fumaroles in the Casa Diablo area appeared in 1982. Another SMSZ swarm occurred in 1983 with 2 *M*>5 earthquakes and an additional 7-cm uplift, modeled as a dike intruding to within 4 km depth beneath the resurgent dome. Seismicity declined thereafter and the uplift rate dropped to less than 1 cm/year.



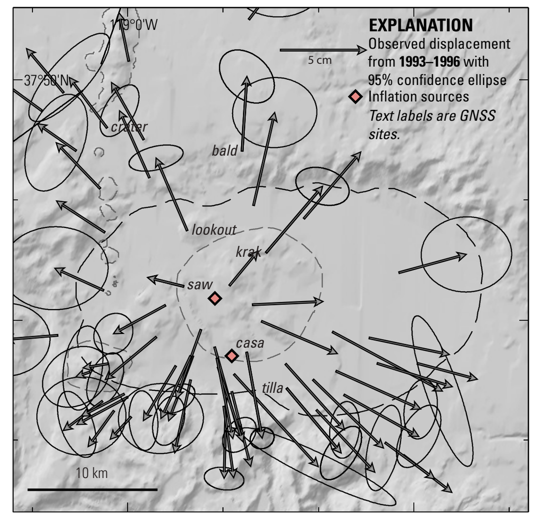


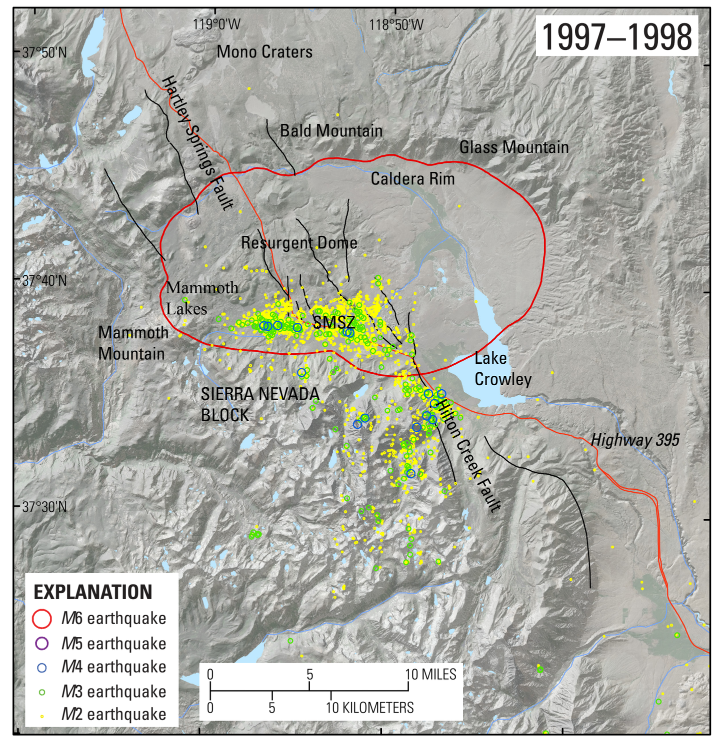
1988–1992: Rapid inflation and 1992 Landers *M*7.3 triggering.
Resurgent dome uplift increased in 1989 to ~7 cm/year followed by an increase in SMSZ seismicity. Inflation slowed to ~2 cm/year by 1990, but SMSZ seismicity continued, peaking with a swarm of >1,000 earthquakes over 4 days in 1991, including 22 *M*>3 events. The deformation sources were located ~6 km and ~12 km below the dome. In 1992, seismic swarms in the SMSZ and Sierra Block were triggered within seconds of the June 28, 1992 *M*7.3 Landers earthquake located ~400 km south of LVC in the Mojave Desert. The distantly triggered swarms included several *M*>3 events.



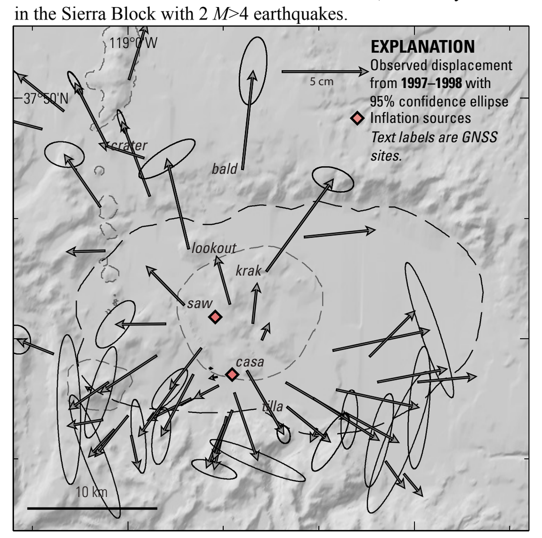


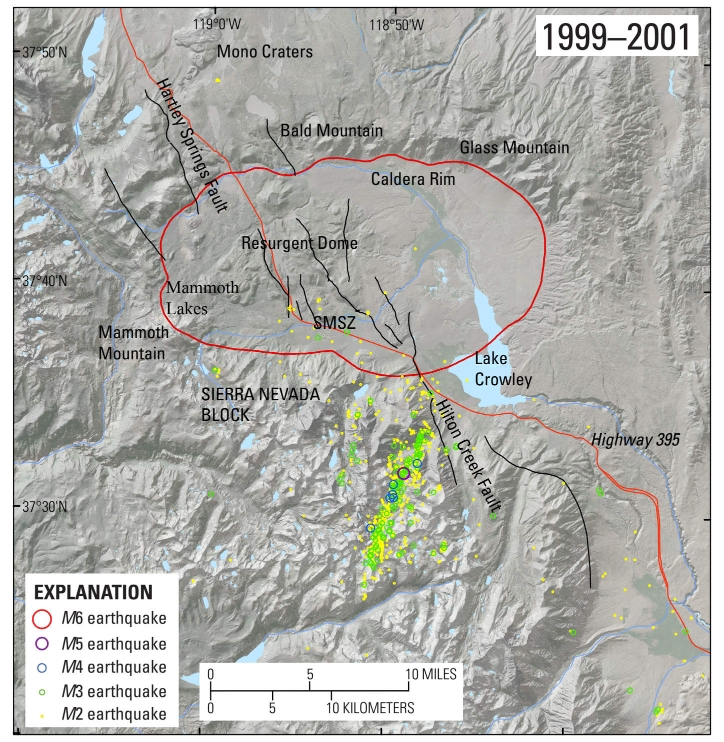
1993–1996: Unusual deformation and seismicity in 1996.
Levels of SMSZ and Sierra Block seismicity and resurgent dome uplift held relatively steady through 1995. In early 1996, an intense swarm of SMSZ earthquakes occurred without a sympathetic uptick in inflation, breaking the pattern of seismicity and deformation rates acting in tandem. The swarm peaked in the spring of 1996 with >1,600 earthquakes over 2 months, including 3 *M*>4 and 21 *M*>3 events.



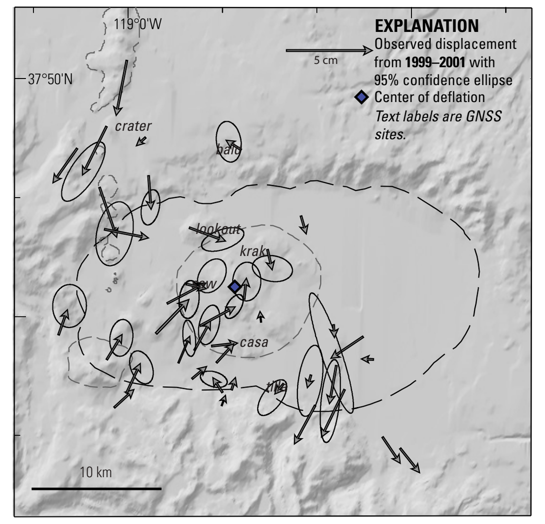


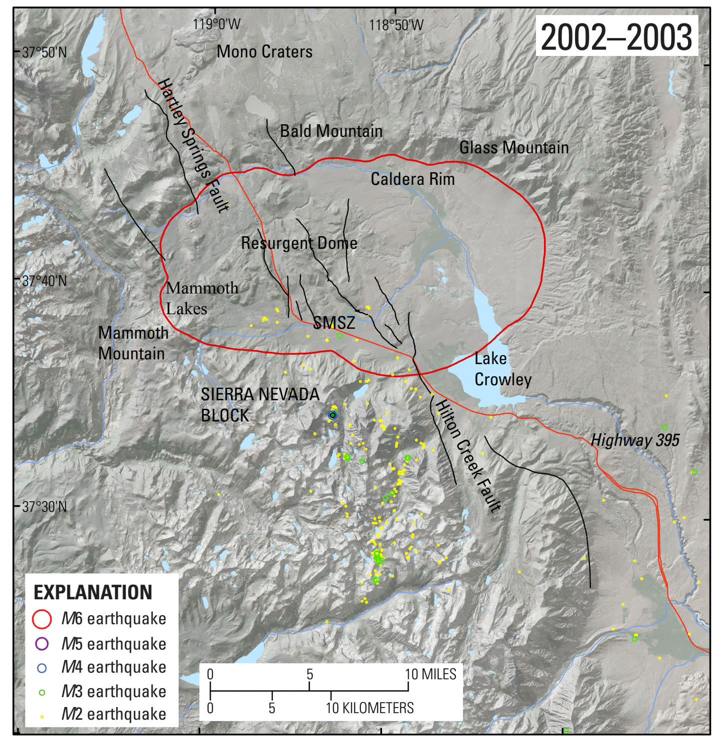
1997–1998: Rapid escalation of caldera unrest.
With the exception of 2 *M*>4 Sierra Block earthquakes in February, relative quiet prevailed through the first half of 1997, giving way to accelerated uplift and SMSZ swarms in the second half of the year. Unrest peaked in late 1997, and then declined through early 1998. Swarms included ~12,000 earthquakes over 7 months, including 120 *M*>3 and 8 *M*>4 events. Peak extension rates up to 2 mm/day ultimately resulted in an additional 10 cm of uplift by mid-1998 before rates declined. In the second half of 1998, seismicity focused in the Sierra Block with 2 *M*>4 earthquakes.



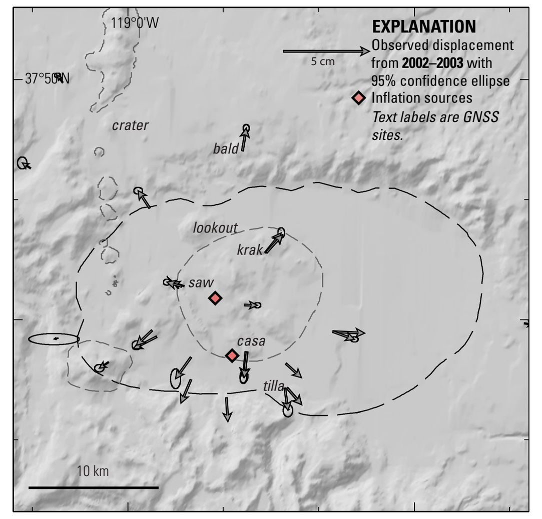


1999–2001: *M*>5 events in Sierra Block but LVC remains calm.
A *M*5.6 earthquake and numerous aftershocks rattled the Sierra Block in May of 1999. The 1999 event, as well as the 2 *M*>4 (both 4.9) events in 1998, had *b* values typical of tectonic earthquakes, and none were followed by increased seismicity or deformation in the caldera. Caldera seismicity remained at background levels with virtually no further inflation of the resurgent dome. In fact, minor deflation was observed.



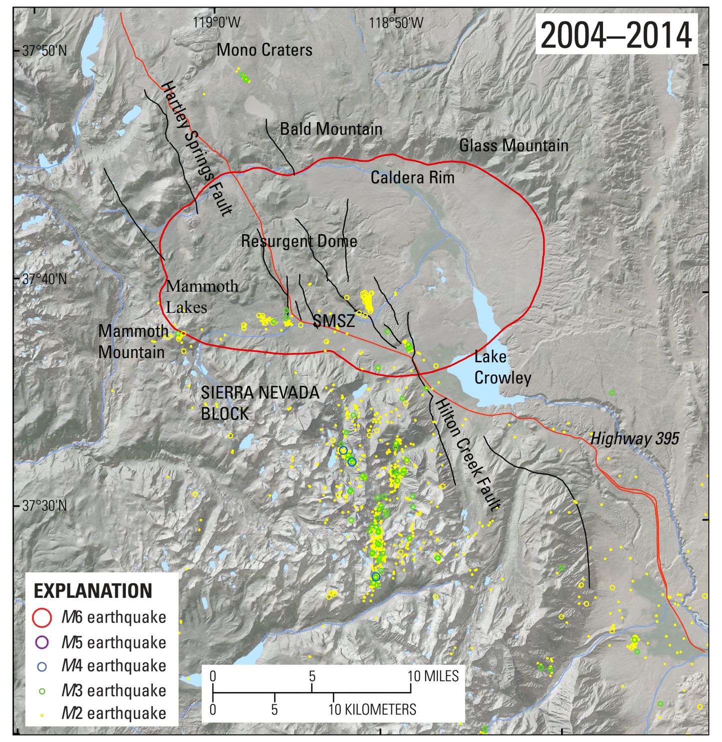


2002–2003: Renewed inflation without swarms.
The resurgent dome started a modest inflationary period in early 2002, ending ~3 years of quiescence. About 3 cm of uplift was added over the year, but SMSZ seismicity stayed at background levels, with the exception of distantly-triggered earthquakes following Alaska's *M*7.9 Denali earthquake on November 3, 2002. Approximately 7 years of relative quiet followed.

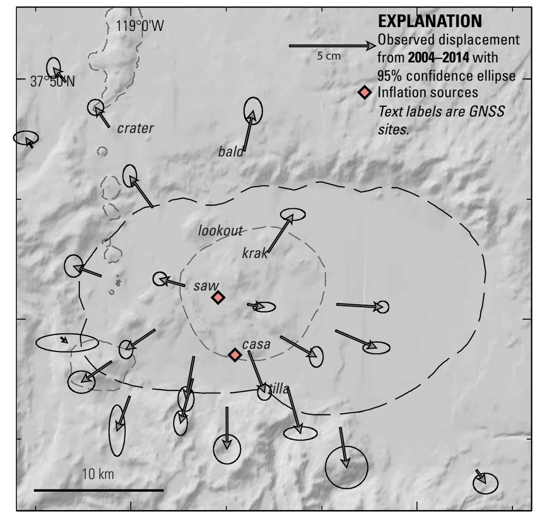


Recent Unrest: 2004–2014

Modest uplift without swarms.

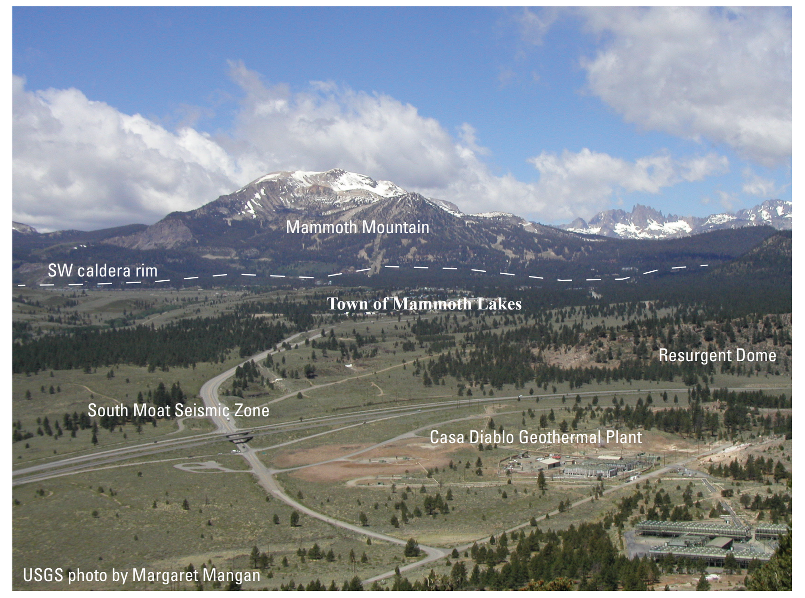


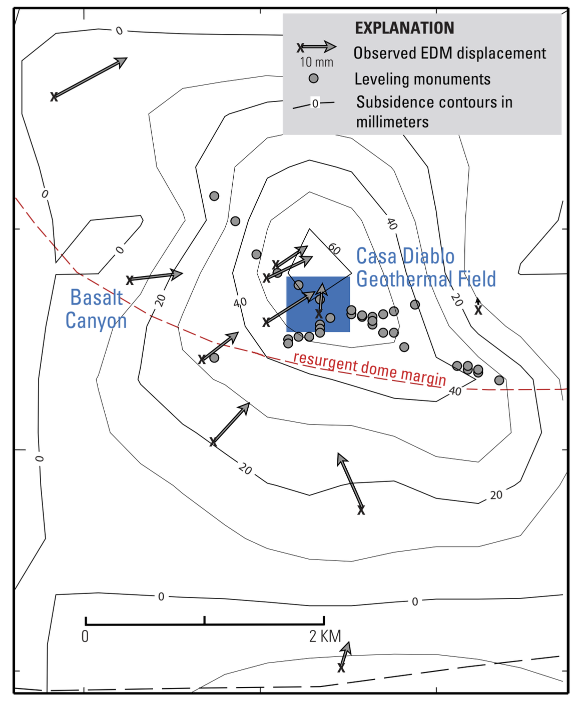
Deformation was flat from 2004 through 2010, and SMSZ seismicity held steady at about 10 *M*1–*M*2 events per month. Seismicity continued in the Sierra Block south of the caldera with many *M*>3 and *M*>4 events. In 2011, after ~8 years of little deformation, the resurgent dome began to inflate at a rate of 2–3 cm/year with little change in SMSZ seismicity. The rate of inflation is similar to that of 2002–2003, on the order of 2–3 cm/yr, and as in 2002–2003, SMSZ seismicity continues at background levels of ~10 *M*1–*M*2 events per month. Preliminary time-dependent modeling of EDM and GNSS suggests a ~0.1 km^3 cumulative volume increase in both deformation sources from 1983 to the present, with negligible contributions since the unrest of 1997-1998, despite the modest inflationary signals of 2002–2003 and 2011–2012. A seismic swarm in June 2013 in the SMSZ included 100 small events with a maximun *M*3.0. Between February 3–18, 2014, a seismic swarm occurred under Mammoth Mountain that included *M*>1 events with a maximum *M*3.1 on February 5. Seismicity in June 2014 included 73 *M*>1 events within a brisk swarm with a maximum *M*2.41.



The influence of geothermal production on volcano monitoring: deformation, geochemical, and thermal monitoring of LVC are locally obfuscated by short-term and long-term changes in the shallow hydrothermal system under the caldera.

Geothermal power production began in 1985 at the Casa Diablo plant located at the southern margin of the resurgent dome. Presently ~40 MW is generated using a counter flow heat exchanger. Hot water at ~170 ˚C is pumped from the shallow thermal aquifer at 150 m depth to heat isobutane which is used to drive turbines. The cooled water at 80 ˚C is then reinjected into a deeper thermal aquifer at ~600 m depth. Water throughput is ~900 kg/s—much larger than the natural ~370 kg/s flow of the shallow thermal aquifer, causing a large impact on caldera hydrology. Thermal contraction at reinjection sites and depressurization at extraction sites give rise to localized subsidence and changes in magmatic gas and heat emission. No strong evidence exists for production-induced seismicity. Potential plant expansion with as many as 8 new wells is under consideration. The photo below shows view of Casa Diablo plant observed from resurgent dome looking westward across the caldera toward Mammoth Mountain.

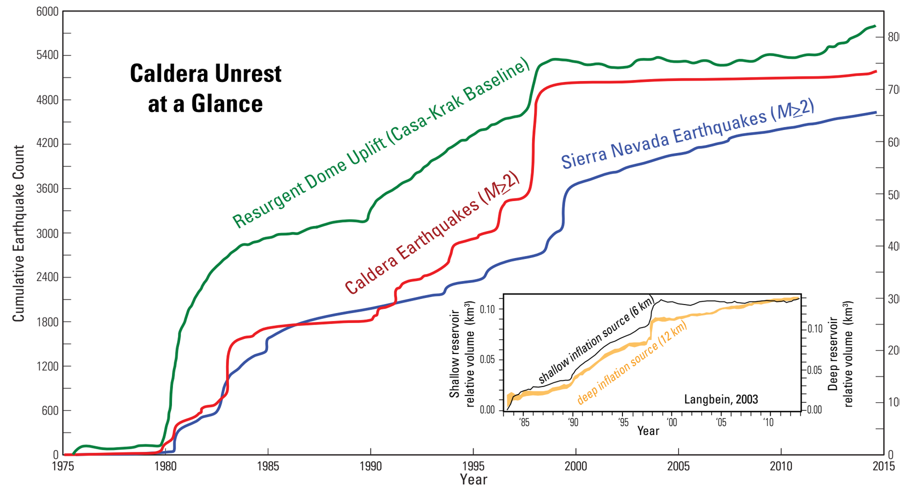




Displacements observed from two-color EDM sites for the interval 1999–2001 show shallow, localized subsidence due to geothermal production. The contours are the estimated collapse in millimeters modeled assuming a 200 m deformation source (known depth of hydrothermal reservoir). Langbein and others, 2003.

Summary of Earthquake Activity and Deformation

Inflation of the resurgent dome from 1975 through August 2014 and earthquake activity plotted in terms of the cumulative number of *M*>2 earthquakes within the Long Valley Caldera and the Sierra Nevada block to the south. Deformation of the resurgent dome is shown from leveling survey lines and EDM through 1997 and frequent measurements with the two-color EDM instrument and GNSS data after 1997. Inset shows modeled volume change of the two reservoirs over time.



References:

Ewert, J.W., Harpel, C.J., Brooks, S.K., and Marcaida, M., 2010, Bibliography of Literature Pertaining to Long Valley Caldera and Associated Volcanic Fields: U.S. Geological Survey Open-File Report 2010–1320, 146 p., and database.

Hill, D.P., Dzurisin, D., Ellsworth, W.L., Endo, E.T., Galloway, D.L., Gerlach, T.M., Johnston, M.J.S., Langbein, J.O., McGee, K., Miller, C.D., Oppenheimer, D., and Sorey, M.L., 2002, Response plan for volcano hazards in the Long Valley caldera and Mono Craters region California: U.S. Geological Survey Bulletin 2185, 57 p.

Langbein, J.O., 2003, Deformation of the Long Valley Caldera, California; inferences from measurements form 1988 to 2001: Journal of Volcanology and Geothermal Research, v. 127, no. 3-4, p. 247–267.

Savage, J.C., 1988, Principal component analysis of geodetically measured deformation in Long Valley Caldera, eastern California, 1983–1987: Journal of Geophysical Research, v. 93, no. B11, p. 13297–13305.

Savage, J.C., and Cockerham, R.S., 1984, Earthquake swarm in Long Valley Caldera, California, January 1983; evidence for dike inflation: Journal of Geophysical Research, v. 89, no. 10, p. 8315–8324.

U.S. Department of the Interior
U.S. Geological Survey

October 2014

ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20141222

Suggested Citation: Wilkinson, S., Hill, D.P., Langbein, J.O., Lisowski, M., and Mangan, M., 2014, Long Valley Caldera 2003 through 2014—Overview of low level unrest in the past decade: U.S. Geological Survey Open-File Report 2014–1222, 1 sheet, http://dx.doi.org/10.3133/ofr20141222.