MIGRATING SWARMS OF BRITTLE-FAILURE EARTHQUAKES IN THE LOWER CRUST BENEATH MAMMOTH MOUNTAIN, CALIFORNIA

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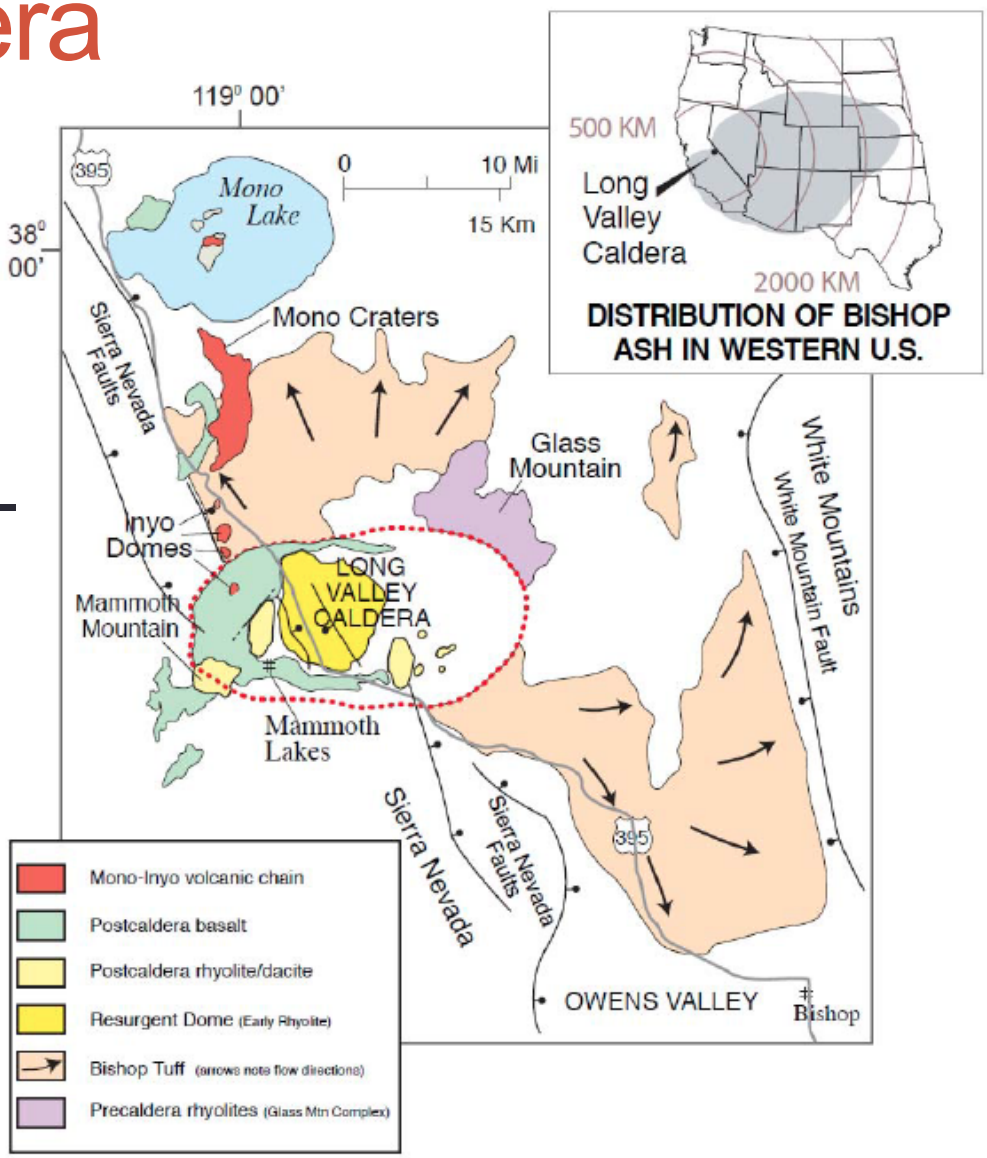
Long Valley Caldera

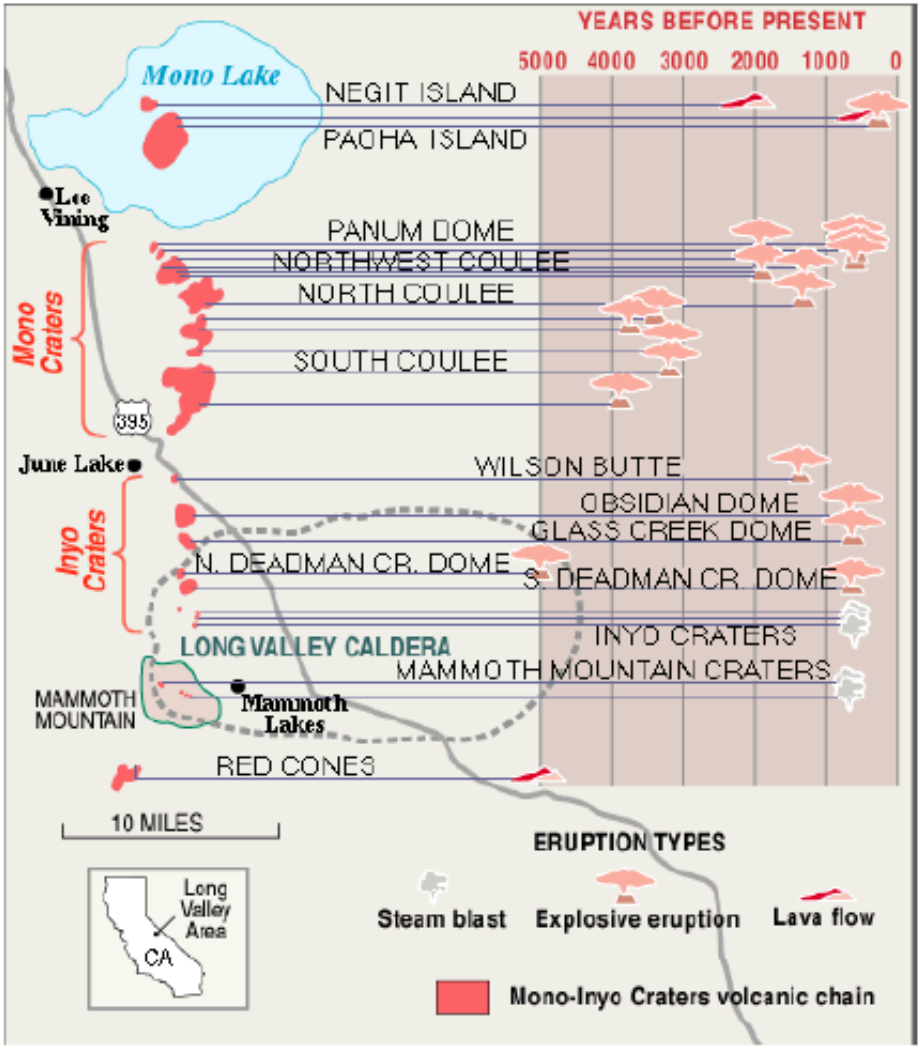
- Long Valley volcanic field (LVVF) includes the Mammoth Mountain and the Inyo-Mono volcanic chain.
- Dominant source of eastern CA volcanism in the past 2 Ma.



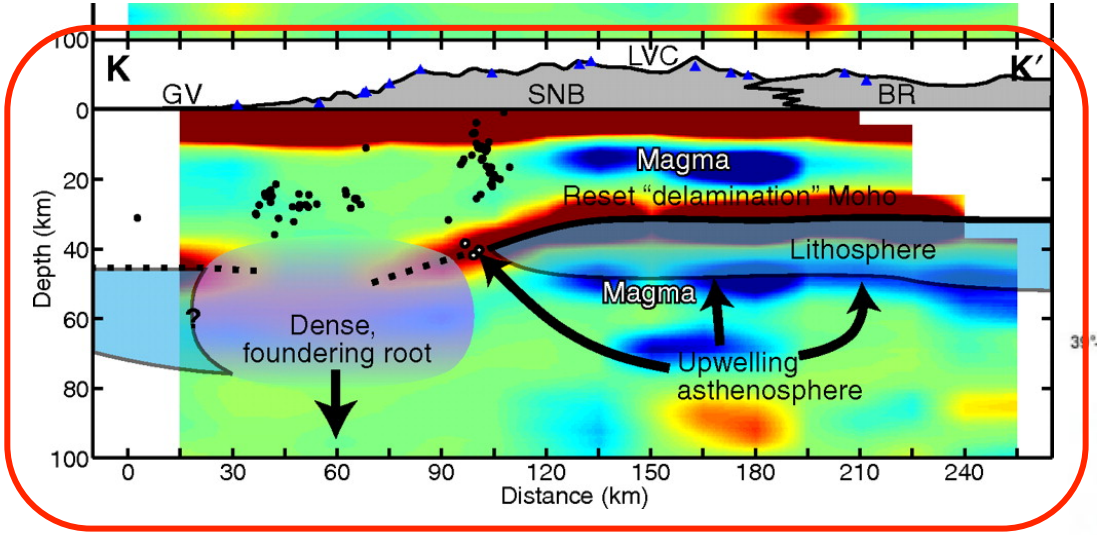
Gene A. Suemnicht

Long Valley Caldera

- Long Valley volcanic field (LVVF) includes the Mammoth Mountain and the Inyo-Mono volcanic chain.
- Dominant source of eastern CA volcanism in the past 2 Ma.
  - Location near the Mina deflection
  - Location above the westward-moving delamination of the lithosphere beneath Sierra Nevada

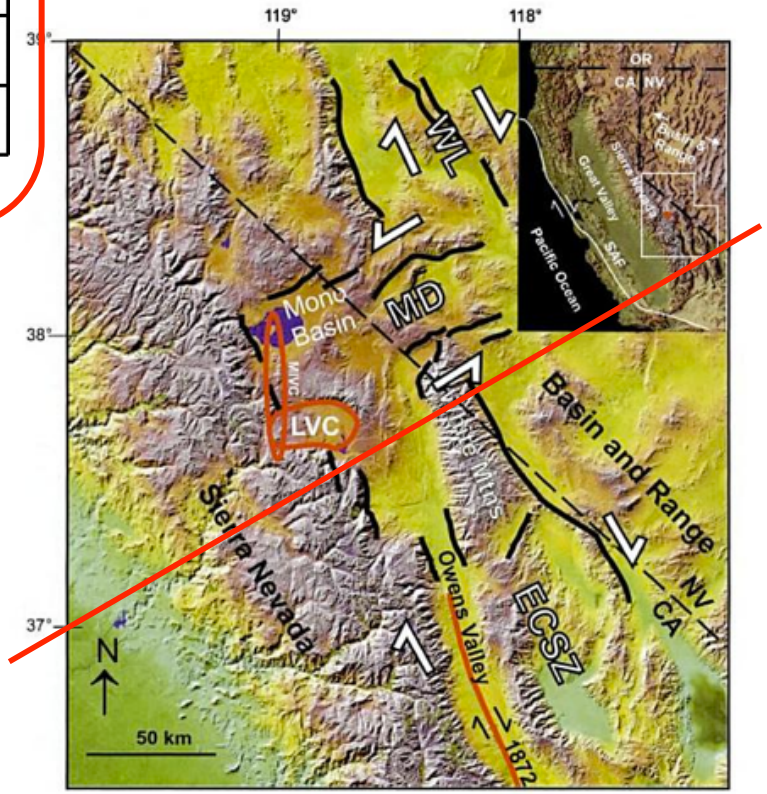


Long Valley Caldera



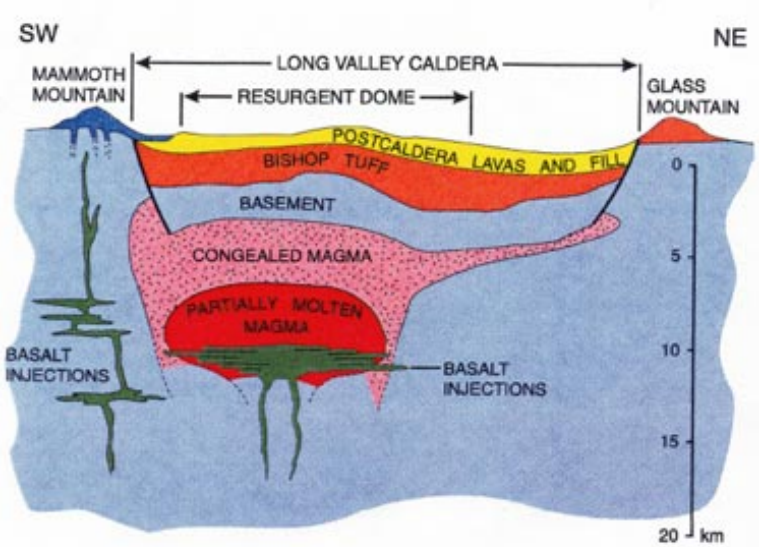
Magma source

Right-stepping left-lateral faults
-Owen's Valley
-Walker Lane
-Mono Basin
-Pre- and Post-caldera structures

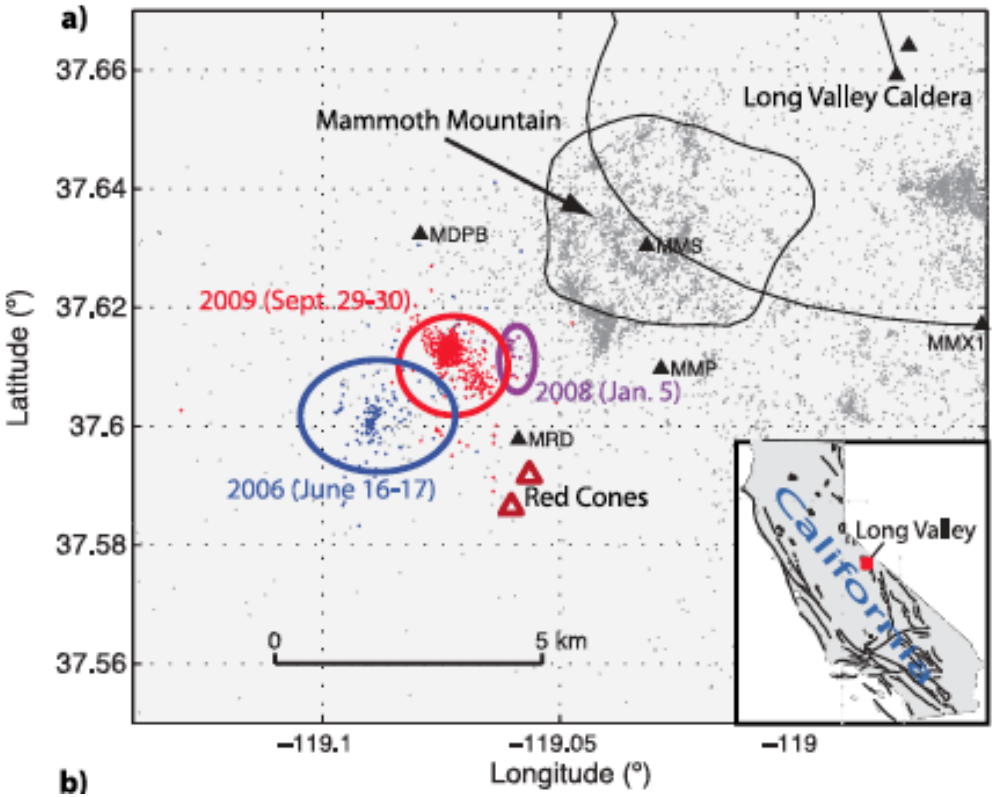


Mammoth Mountain

- Surrounded by mafic volcanic vents
  - Basaltic magma eruptions 200-8 ka
- Volcanic unrest from 1980 to 2000
  - Number of EQ swarms
  - M6 near the caldera in May, 1980
  - Uplift of the resurgent dome by 80 cm
  - 1989-1990: 11-month-long swarm at Mammoth Mountain



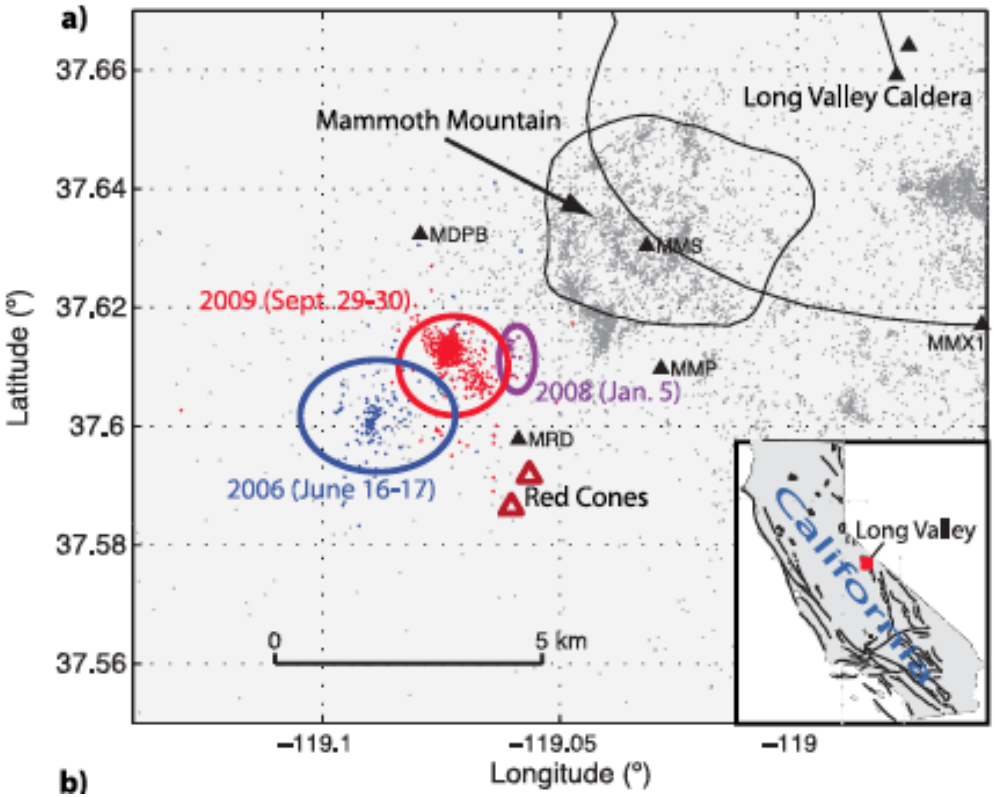
Seismicity

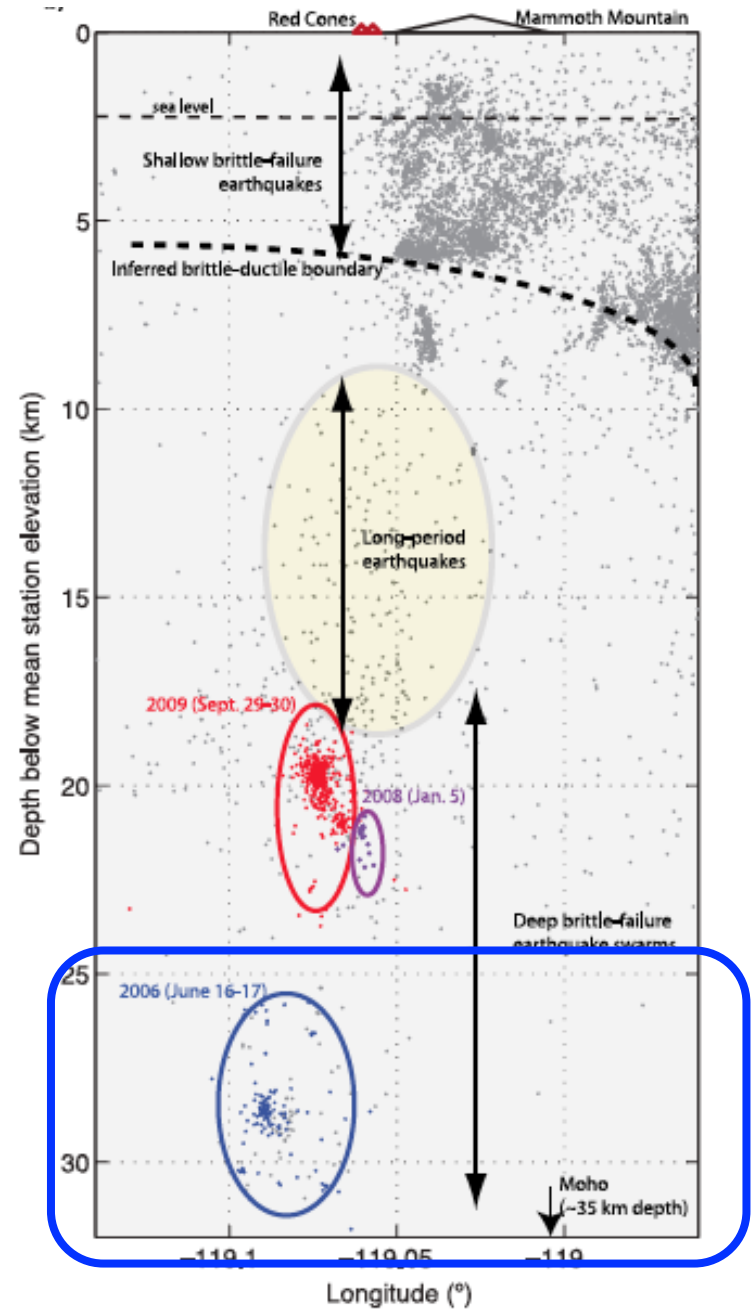


- Brittle failure in upper 8-km, often as swarms and sequences of overlapping events
- LP events in the mid-crust
- Short-duration swarms (brittle failure)

- Microseismicity 1984-2008
- 2006: 53 → 140
- 2008: 8 → 21
- 2009: 55 → 602

Seismicity





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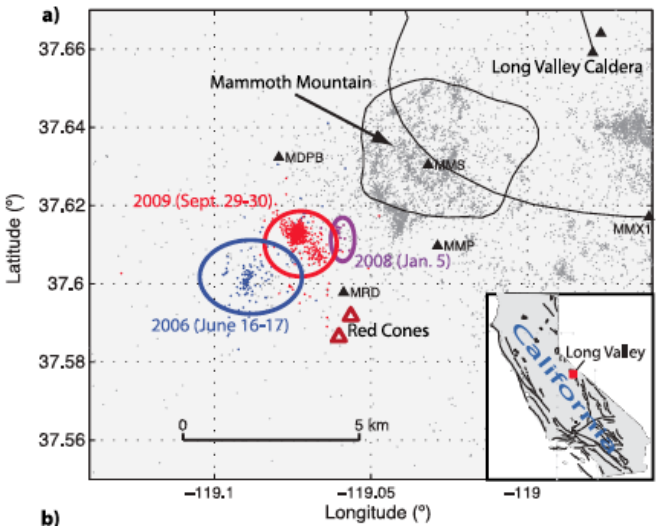
Deep brittle-failures beneath volcanoes

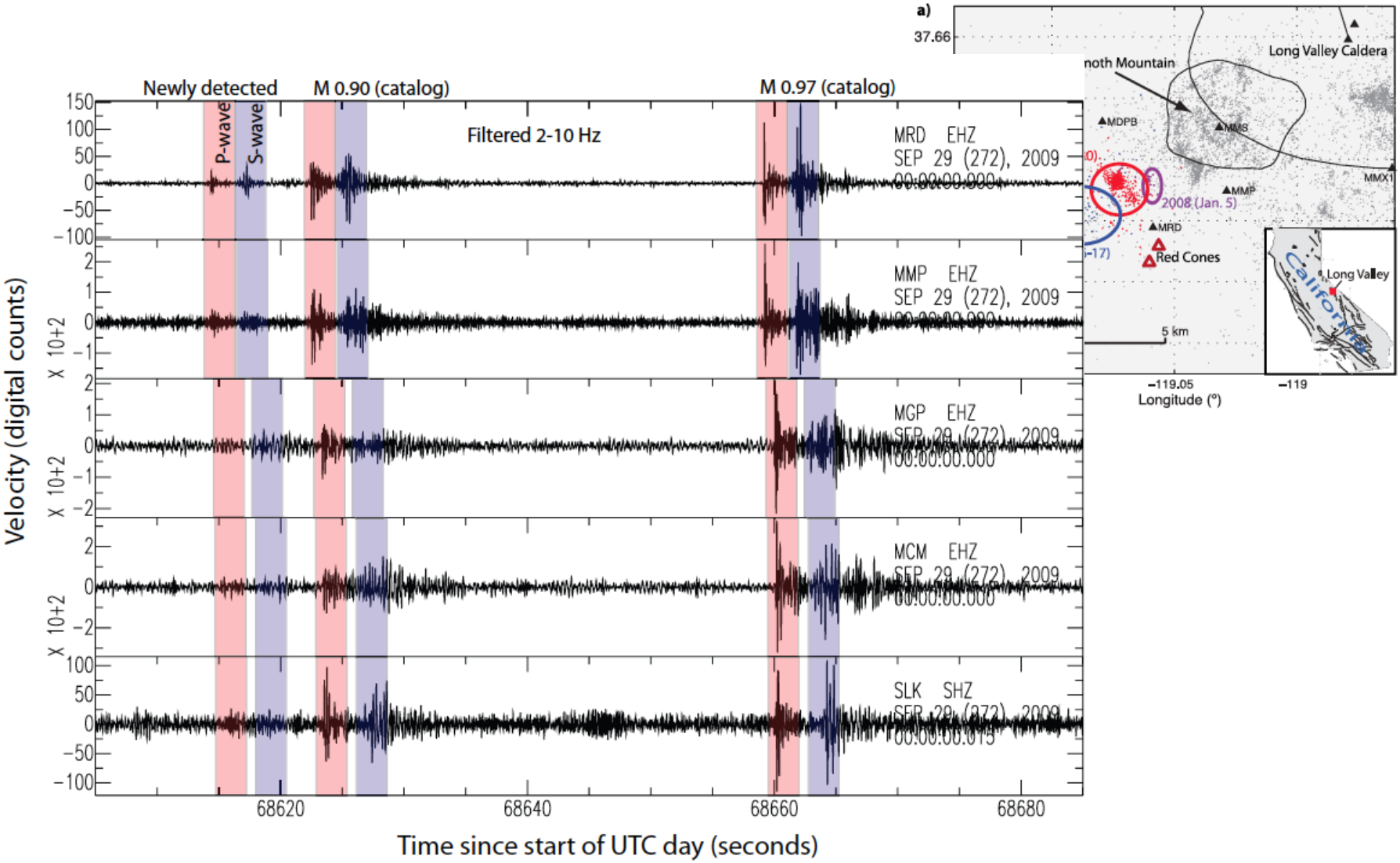
- Kilauea in Hawaii
- Northern volcanic rift zone in Iceland
  - Events below brittle-ductile transition
  - Bursts (hours) propagated up and down
  - Long-term (weeks) upward migration observed
- Taupo Volcanic Zone in New Zealand
- Aleutian arc volcanoes in Alaska
- Lake Tahoe, California (likely)
  - ~200 km NW of Long Valley
  - August, 2003
  - Upward migration
  - 8 mm of uplift and 6 mm horizontal displacement from GPS

Data and methods

- Main objective
  - Identify similar small EQs & relocate events
  - Using waveform cross-correlation and double-difference
- Data
  - Long Valley Caldera seismic network
  - Short-period, vertical component



Data and methods



Data and methods

- Main objective
  - Identify similar small EQs & relocate events
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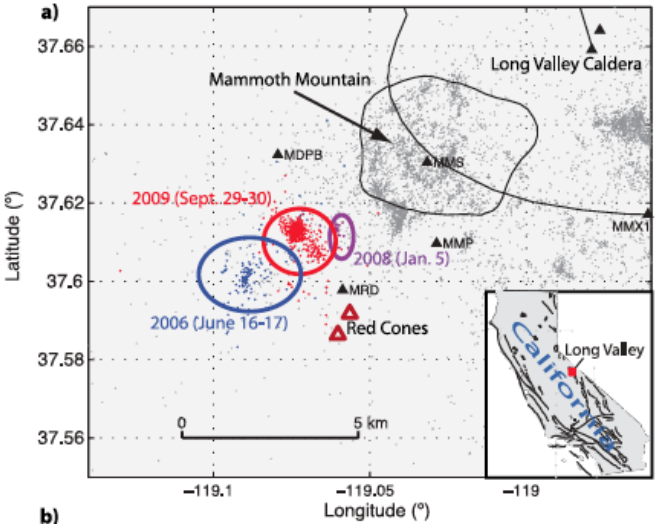
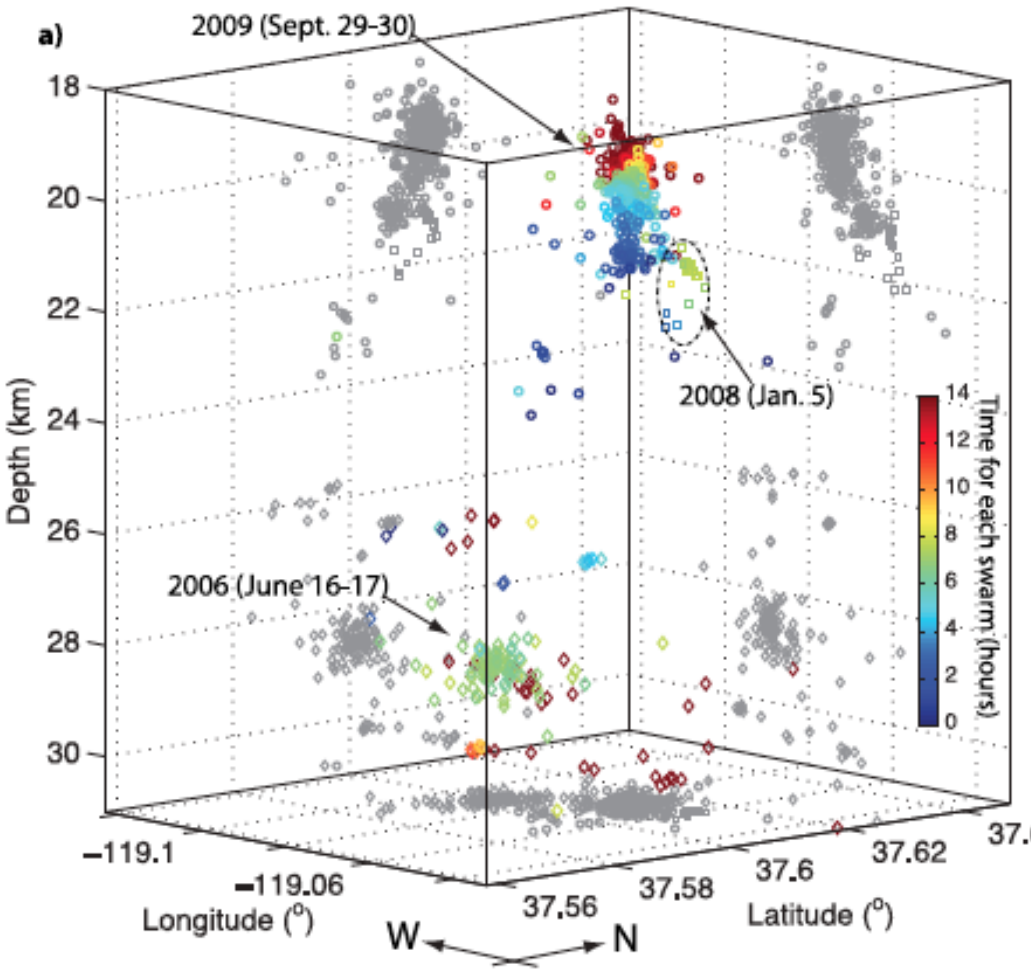
- Data
  - Long Valley Caldera seismic network
  - Short-period, vertical component
- Event Detection
  - P and S waveform templates from NCSN, 2-10 Hz, 2.5 seconds long
  - Correlation above background noise, events don't need to be identical
- Event location
  - double-difference location (hypoDD)
  - Includes catalog P and S arrival times



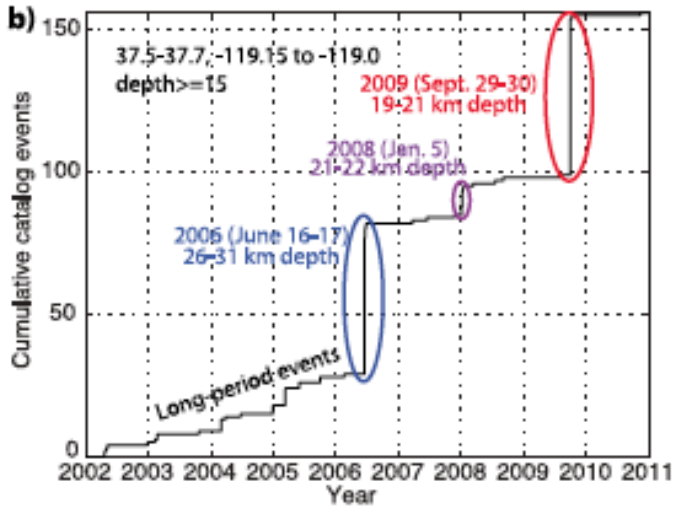
Space-time progression

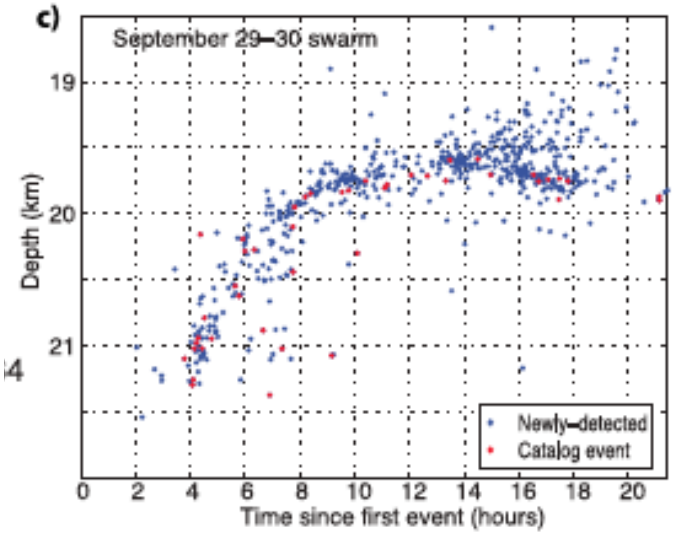


- 2006 sequence
  - deep and diffused
  - Waveforms less similar
- 2009 sequence
  - Begins where the 2008 sequence terminates
  - Very similar waveforms

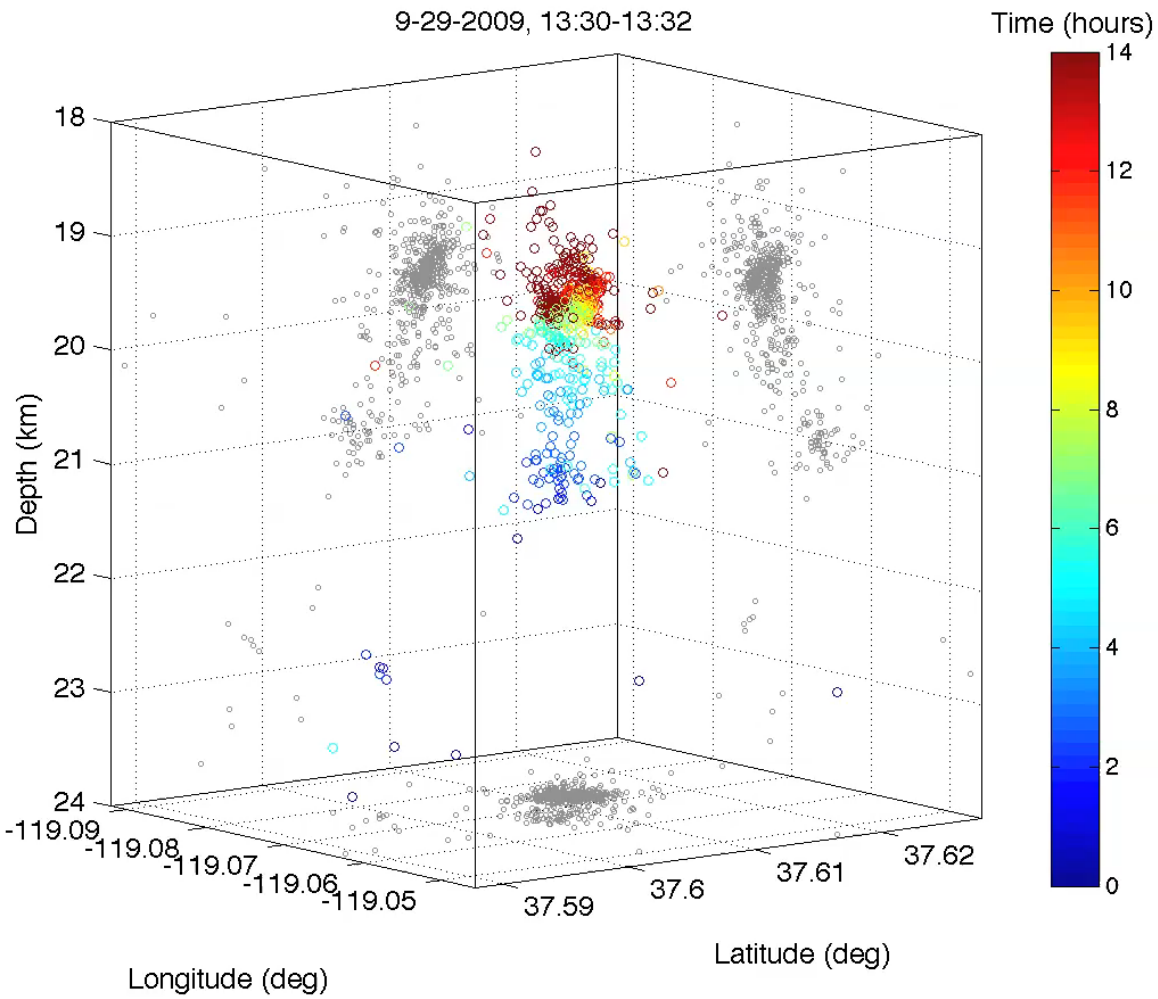
Space-time progression

- Cumulative catalog events
  - Events greater than 15 km
  - Referenced to mean station elevation ~2.5 km above sea level
- Systematic decelerating upward migration
  - Red dots: already catalogued
  - Blue dots: newly detected

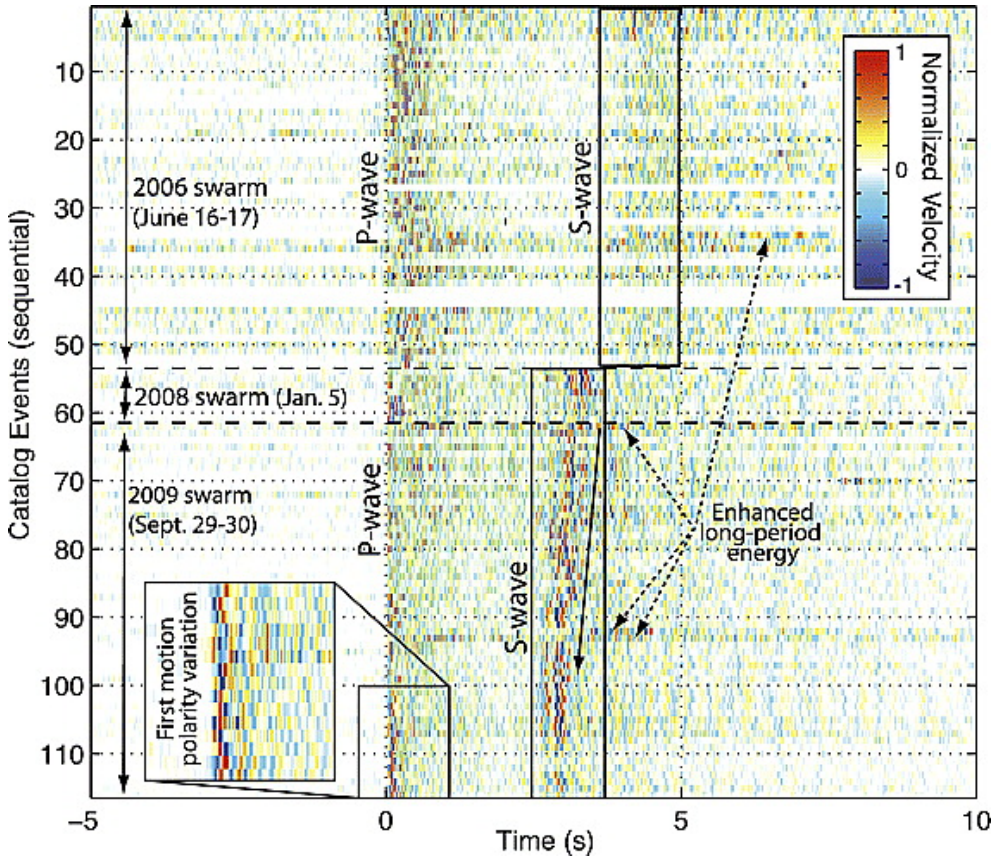




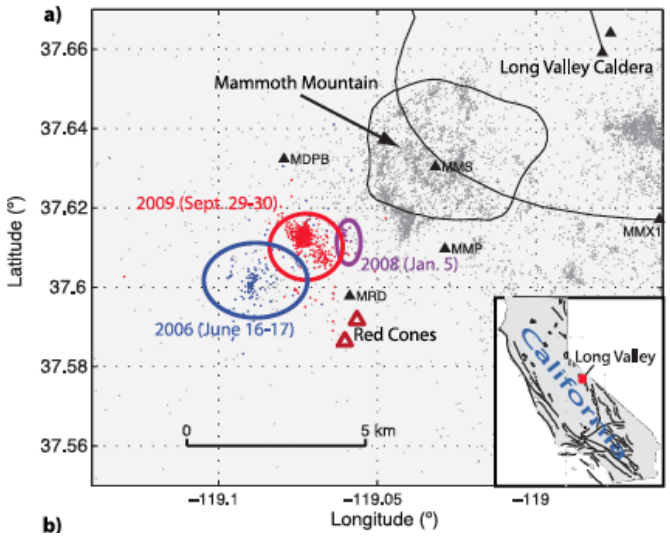
September 29-30, 2009 swarm



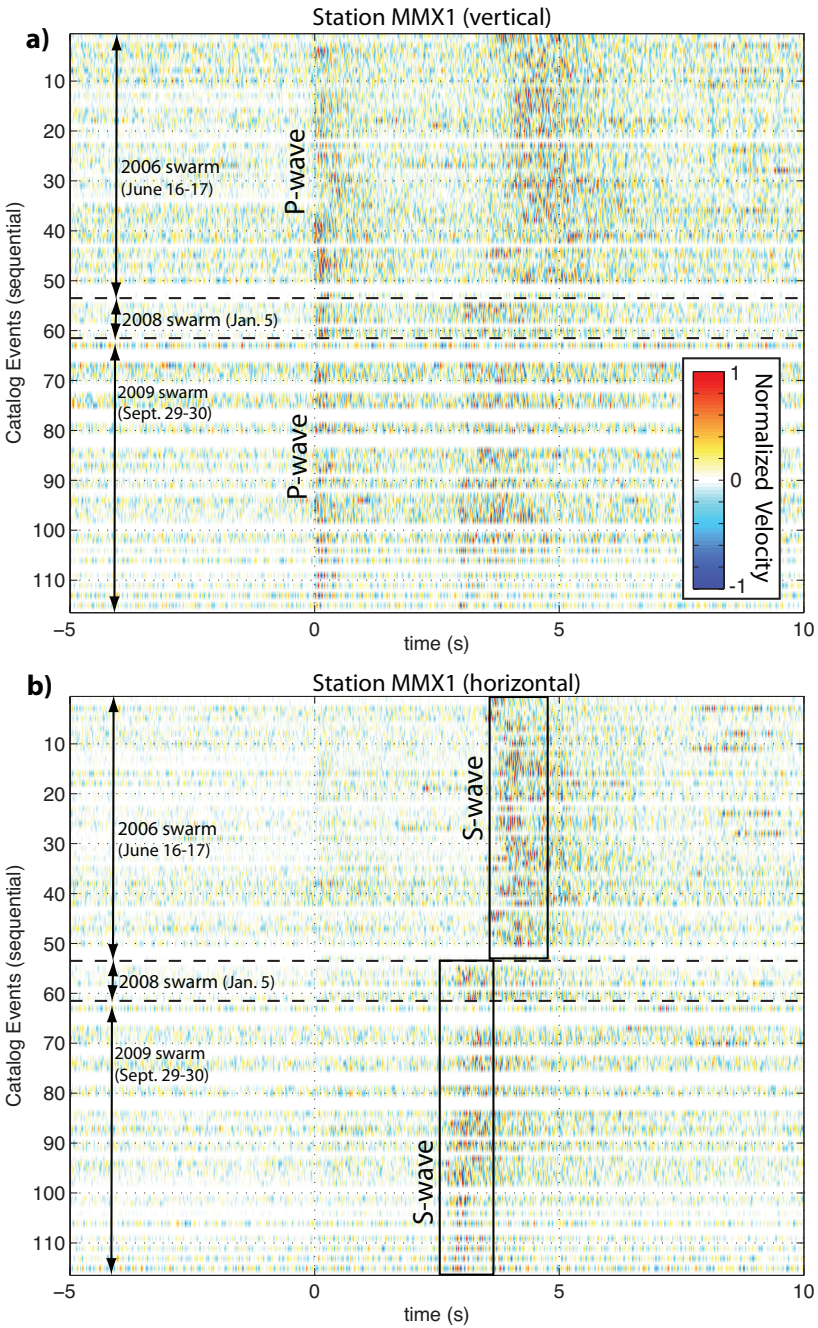
Waveforms



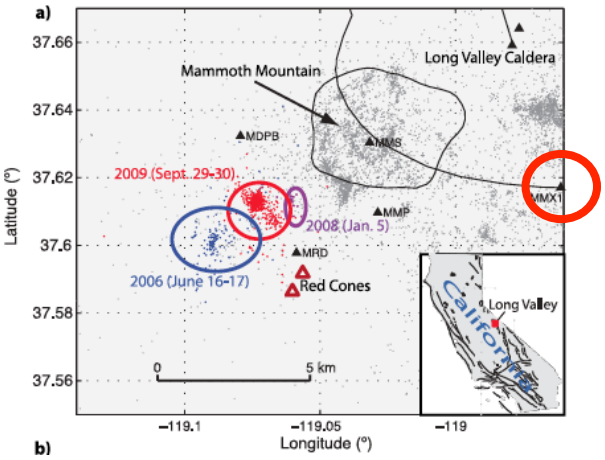
- Decreasing S-P times in 2008 and 2009; longer S-P times in 2006
- S arrival times consistent
- MRD shows weak S-waves in the 2006 swarms



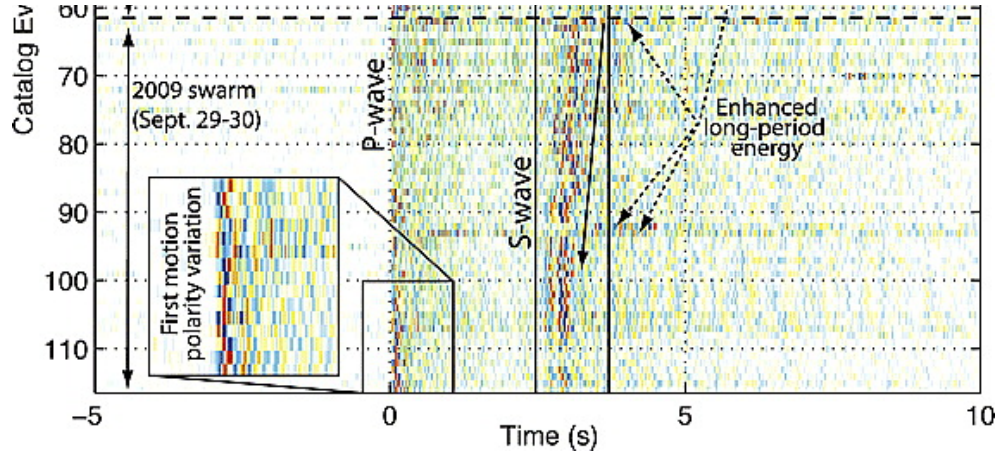
Waveforms

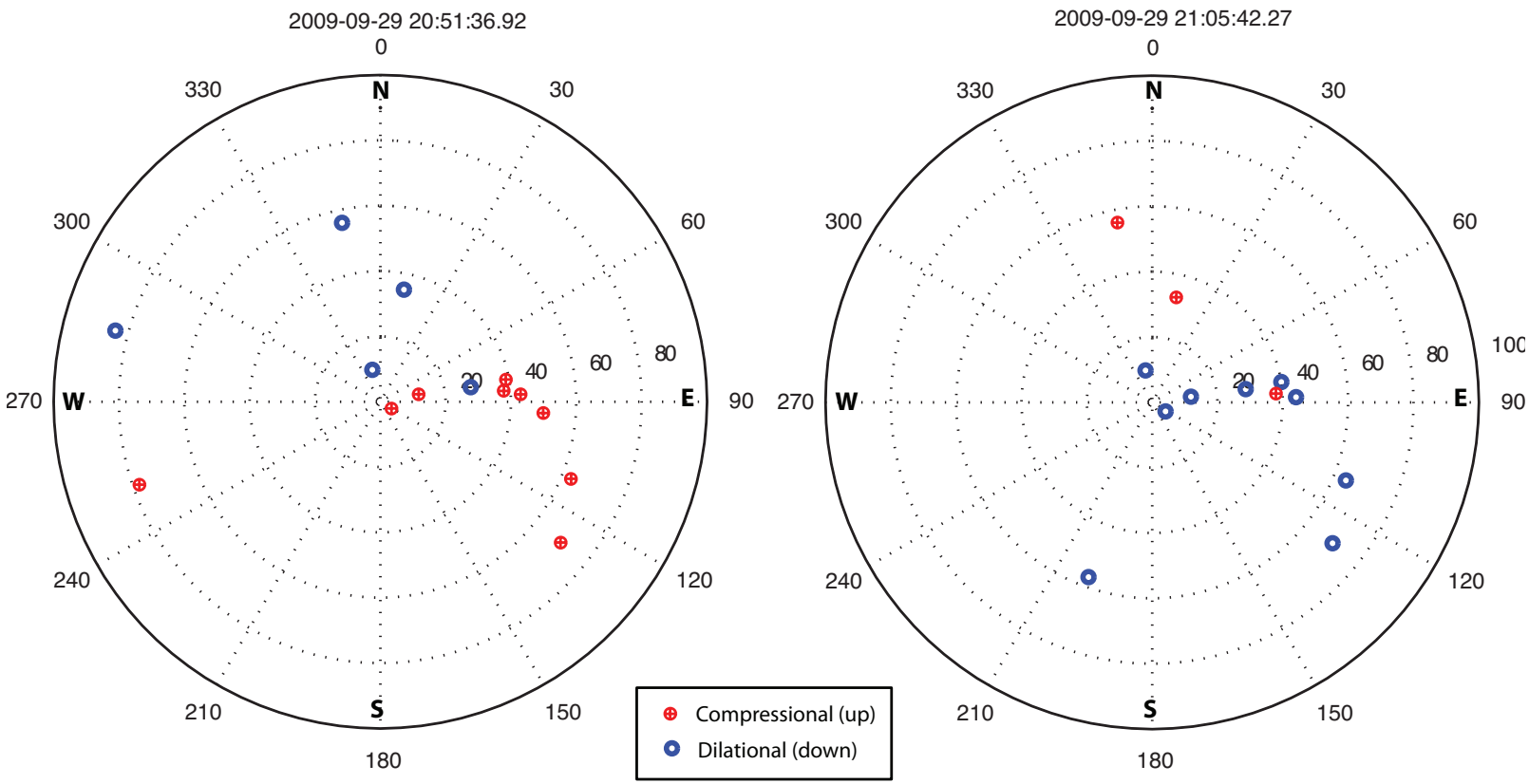


- Decreasing S-P times in 2008 and 2009; longer S-P times in 2006
- Variations in S wave amplitudes between different stations
  - High attenuation above MRD or different distribution of focal mechanisms



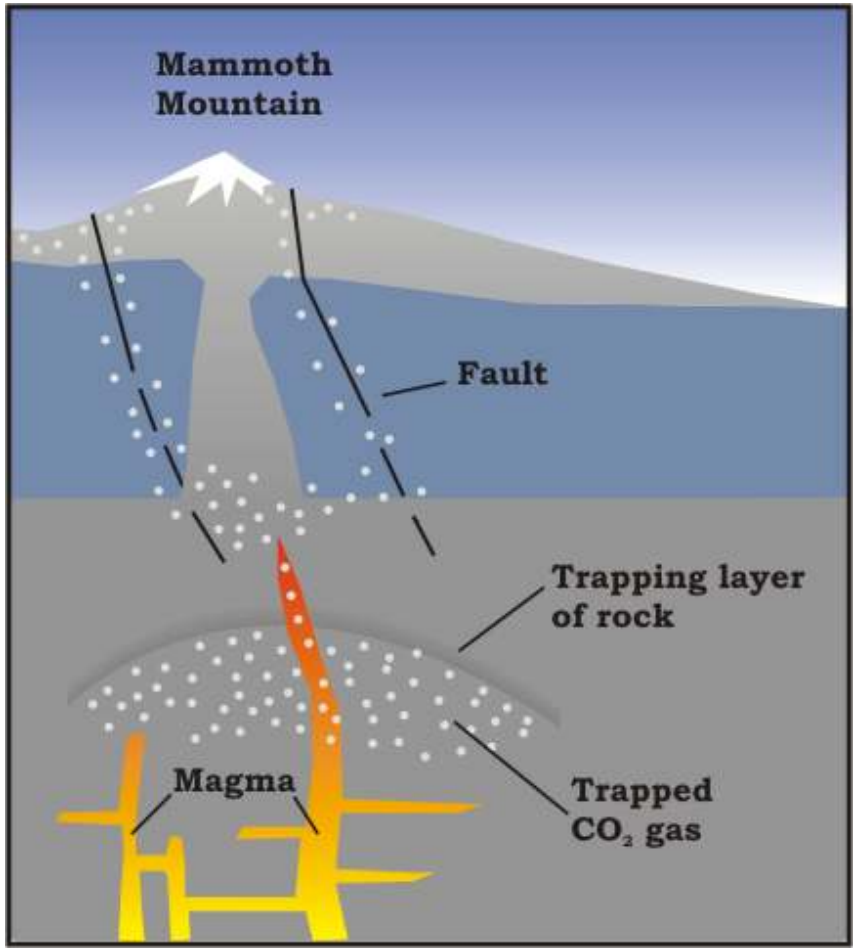
First motions





Source mechanism(s)

- Fluids – magma, CO_2, or water
- Hydrofracturing or slip on pre-existing fracture
- Fluid diffusion or migrating fluid pressure pulse
- 2009 swarm – faster fluid migration rates
  - Viscosity
  - Diffusion of CO_2-rich fluid



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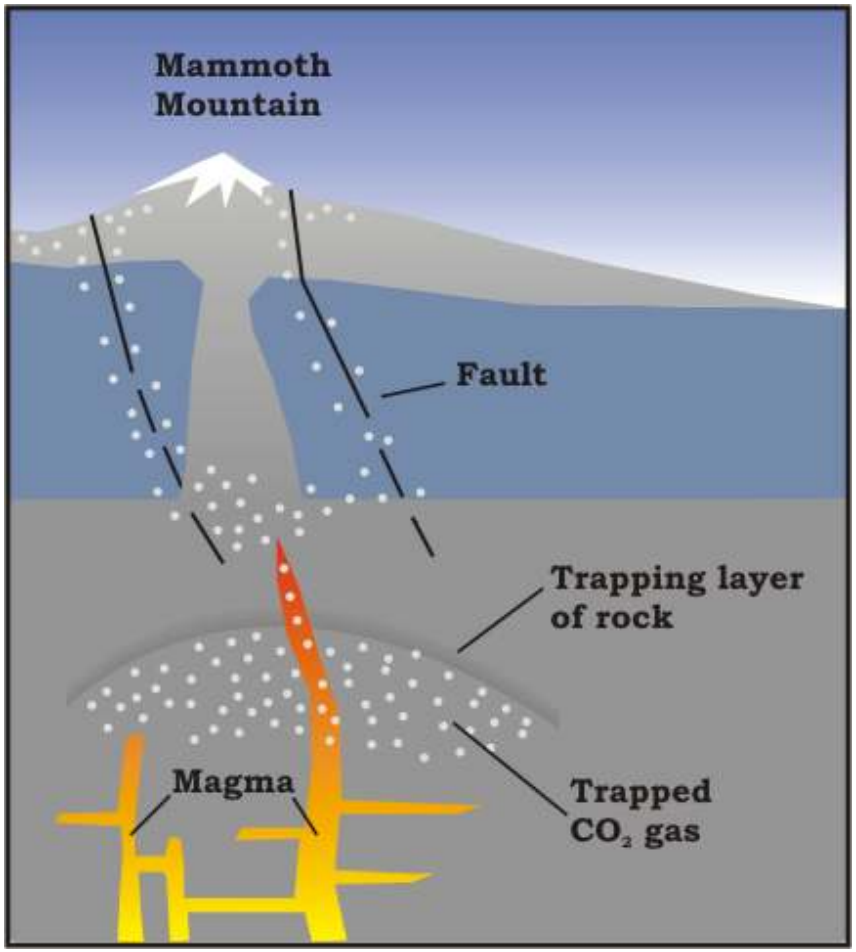
Source mechanism(s)

- Pressurized CO_2
  - Short duration
  - Smaller magnitudes
  - Fast migration
  - Similar to Iceland Swarms
  - Supercritical at lower crustal conditions
  - Lower viscosity than magma
  - High concentration of CO_2 gas at the surface
- Diversity in source mechanism



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Take-home message

- Brittle failure in the lower crust induced by fluid injection and migration

- Speed, duration and lower magnitudes of the 2009 swarm suggest migration of CO_2 released from underlying magma