Absolute Location of 2019 Ridgecrest Seismicity:
Duplex Mw6.4 Ruptures,
Migrating and Pulsing Mw7.1 Foreshocks,
Unusually Shallow Mw7.1 Nucleation.

Did the Mw7.1 rupture require incitation by Mw6.4-like rupture?

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Calibrated absolute location of M$\geq$1.0 Ridgecrest events

Absolute earthquake location forms a foundation and framework for earthquake response and basic seismological studies.

Here we examine *calibrated* absolute relocation with:

- different 1D and 3D velocity models
  
  **1D**
  - SC1D - constant-velocity layered, 1-D, Southern California (Kanamori and Hadley, 1975)
  - HK1D - smooth version of SC1D (Plesch et al., 2011)
  - L1D - smooth, 1D model (Lin et al, 2007)

  **3D**
  - CVMH3D - SCEC CVM-H 3D: topological/bathymetric, basement, and Moho surfaces (Plesch et al., 2011)
  - ZL3D - smooth, 3D, tomographic model for the Coso-Ridgecrest area (Zhang and Lin, 2014)

- probabilistic, global-search location algorithm: robust to model and arrival-time error
  

- station corrections
  
  developed using 278 USGS M$\geq$2.5 events after July 12, 2019, when nearby, temporary stations installed
Study area and relocated seismicity: post-Mw6.4 (color), post-Mw7.1 (dark gray)

Timeline of displayed seismicity →

Ridgecrest, California sequence: July 2019
Relocated seismicity: post-Mw6.4 (color), post-Mw7.1 (light gray)

Understand the seismicity in 3D:
An animation of absolute relocations of $M \geq 1.0$ Ridgecrest seismicity with interpreted faulting structures:

click here → Ridgecrest2019_ALomax_M1_Faulting_movie
Different seismic velocity models give different depth ranges for seismicity.

- Model: SC1D
- Model: HK1D
- Model: L1D
- Model: CVMH3D
- Model: ZL3D

**Preferred model**: ZL3D

**Template-matching relative location**: Ross et al. 2019

**USGS catalog**: earthquake.usgs.gov

Layer artifacts
The seismicity is mainly ~3-12km deep, with few shallower events.
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A similar depth range for seismicity is found elsewhere in California, for example:

Calibrated relocations from 1966 to 2005 for the Parkfield segment of the San Andreas Fault

*Thurber et al., 2006*
Mw7.1 location is complicated by overlapping waveforms from a small, M6.4 aftershock

Re-picked stations closest to Mw7.1 epicenter

Small aftershock of the Mw6.4 event

Re-picked Mw7.1 mainshock

0.5 sec vertical component seismograms
The Mw6.4 hypocenter is ~12km deep, the relocated Mw7.1 hypocenter is unusually shallow at ~4km.
Post-Mw6.4 seismicity defines orthogonal, duplex faulting structures → the Mw6.4 event is a double earthquake.
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Mw6.4 duplex faulting structures
little or no overlap

surface ruptures (EERI)

Mw6.4 duplex faulting structures
Timeline of seismicity: several hours of pre-Mw6.4 seismicity occurs at ~12km depth, near the future Mw6.4 hypocenter.
The Mw6.4 hypocenter and rupture initiation is at ~12km depth

Seismicity up to the Mw6.4 event
Post-Mw6.4 seismicity defines duplex faulting structures → the Mw6.4 event is a double earthquake
Post-Mw6.4 seismicity defines duplex Mw6.4 faulting structures: rupturing first a deep, SE-NW faulting structure to 6 hours after Mw6.4 event.
Post-Mw6.4 seismicity defines duplex Mw6.4 faulting structures: then rupturing a shallower, NE-SW faulting structure.
Post-Mw6.4 seismicity defines duplex faulting structures: and illuminating a crossing structure to the NW

seismicity to 6 hours after Mw6.4 event
Post-Mw6.4 seismicity extends towards the Mw7.1 hypocenter, and small clusters of events activate near the future Mw7.1 hypocenter.
Post-Mw6.4 seismicity extends towards the Mw7.1 hypocenter, with an Mw5.4 event illuminating a new crossing structure to NW.
Small clusters of events near the future Mw7.1 hypocenter activate in pulses up to Mw7.1 initiation.
Post-Mw7.1 seismicity defines ~55km long, near-vertical, SE-NW structures
Pre-Mw7.1 seismicity extends towards the Mw7.1 hypocenter, with an Mw5.4 event illuminating a new crossing structure (6.4NWx2).
Small clusters of events near the future Mw7.1 hypocenter activate in pulses up to Mw7.1 initiation.
The seismicity suggests: Mw7.1 rupture initiation activated as an event in the pulsing clusters, ...
... early Mw7.1 rupture growth was *primed* by stress changes from Mw6.4 rupture and aftershocks, ...
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Coulomb stress change on Mw7.1 fault plane due to Mw6.4 rupture is *positive* near future M7.1 hypocenter
... early Mw7.1 rupture growth was *primed* by stress changes from Mw6.4 rupture and aftershocks, ...
thus, Mw7.1 nucleation at shallow depth may have *required incitation* by the Mw6.4 event.

The Mw7.1 hypocenter falls in a shallow zone with physical properties not conducive to spontaneous rupture nucleation and growth of large earthquakes.
otherwise, Mw7.1-like rupture might not have occurred until long in the future:

through incitation by another, deep, Mw6.4-like event,

or with nucleation at greater depth,

or perhaps rupture on a different, nearby fault might relieve the tectonic strain energy.
otherwise, Mw7.1-like rupture might not have occurred until long in the future:

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or perhaps rupture on a different, nearby fault might relieve the tectonic strain energy.

This scenario greatly complicates hazard assessment:

It implies that the occurrence of some large earthquakes depends not only on rupture zone properties, state of stress, and nearness to end of some “seismic cycle”, but also on incitement by a nearby, deeper, perhaps smaller event.
Conclusions

Robust, absolute earthquake location for Ridgecrest defines faulting structures and evolution of seismicity.

The Mw6.4 event ruptured two, non-intersecting, duplex structures; the Mw7.1 hypocenter is unusually shallow.

Mw7.1 nucleation may have required incitation by the Mw6.4 event, which greatly complicating hazard assessment.

Further information, preprint and links: http://alomax.net/projects/Ridgecrest_2019

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Relocated seismicity: post-Mw6.4 (color), post-Mw7.1 (light gray)

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References


