# *Order and timing of high-angle conjugate strike-slip faulting in Walker Lane sequences*


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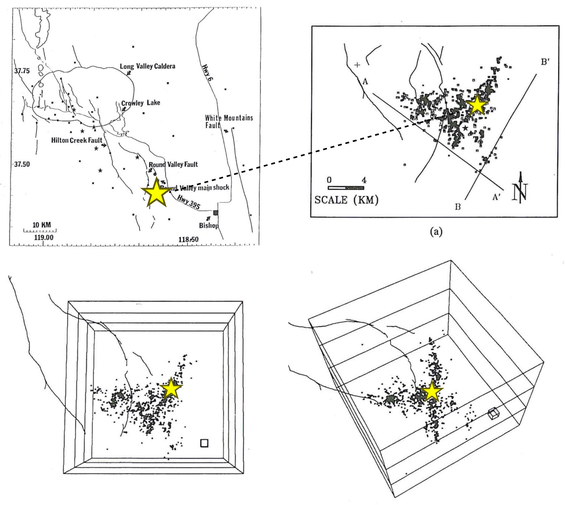
***Abstract***

With the 2019 Ridgecrest sequence displaying a conjugate strike slip faulting geometry it is worth noting other Walker Lane earthquake sequences that show a similar behavior. The initial July 4 M6.4 NE striking Left-Lateral (LL) Ridgecrest event was followed on July 5 by the Right-Lateral (RL) NW striking M7.1 main shock (Lomax, 2020 and Ross et al. 2020, have modeled additional complexities in the foreshocks). This order and geometry of faulting is observed in nearly all recent moderate sized (M>=~5.7) high-angle strike slip sequences in the Walker Lane region. A sequence of 4 M6 earthquakes in 1980 in the Long Valley area began with an M6 NE striking LL event south of the Caldera followed by an M6 WNW striking RL event in the south Caldera. The 1984 Round Valley sequence east of Long Valley began with the M5.9 NE striking LL mainshock followed by development of a NE dipping NW striking conjugate structure (Priestley et al., 1988). The 1986 Chalfant sequence, ~15 km east of Round Valley, began with an NE striking M5.7 LL event followed 24 hours by the M6.3 northwest striking RL mainshock, defining a conjugate geometry (Smith and Priestley, 1988, 2001). The 1987 Superstition Hills sequence also progressed from an initial LL to a RL high-angle event in a conjugate faulting geometry (Magistrale et al., 1989). The1994 M5.9 NE striking Double Springs Flat, Nevada LL strike slip event was followed by the development of an intersecting NW striking RL structure in a conjugate geometry identified in aftershock relocations (Ichinose et al., 1988). Three M5 events of the 2003-2004 Adobe Hills sequence east of Mono Lake, CA, included off-fault structures but less clear conjugate features in the closely spaced sets of high-angles faults in the Adobe Hills volcanic area. Three M5s (Mw5.9, Mw5.8 and Mw5.7) and aftershock relocations for the 2015 Nine-Mile Ranch, Nevada, sequence define a NE-SW striking conjugate fault geometry (Hatch et al, 2020) with the initial M5.8 most likely on the NE striking LL structure following immediately by an M5 NW striking high-angle RL event. With the prevailing T-axis orientated at a high-angle to an initiating NE striking structure suggests that sequences may be triggered by reducing normal stresses on the initiating faults yet primary long-term strain in the Walker Lane is oriented NW parallel to the plate boundary and accounted for in NW striking RL faulting.


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## *1984 M5.9 Round Valley - SE of Long Valley*

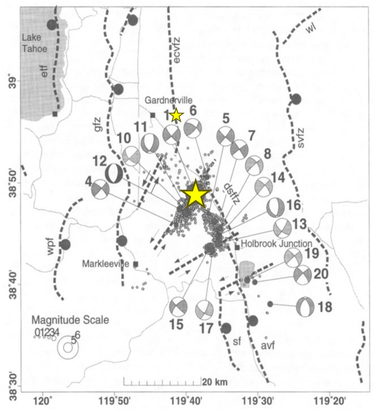
The 1984 Round Valley sequence (Mainshock - 11/23/1984:18:08:25 UTC - yellow star) initiated with the M5.9 NE striking left-lateral high angle mainshock. The initial 6 hours of aftershocks are confined to the NE striking mainshock fault structure. The conjugate NW striking NE dipping structure, right-lateral offsets, was defined within 30 hours of the M5.9. The conjugate structure can be recognized in 3-D perspective view.




***Priestley, Smith, Cockerham, 1985***

## *1994 Mw5.8 Double Springs Flat SE of Lake Tahoe*

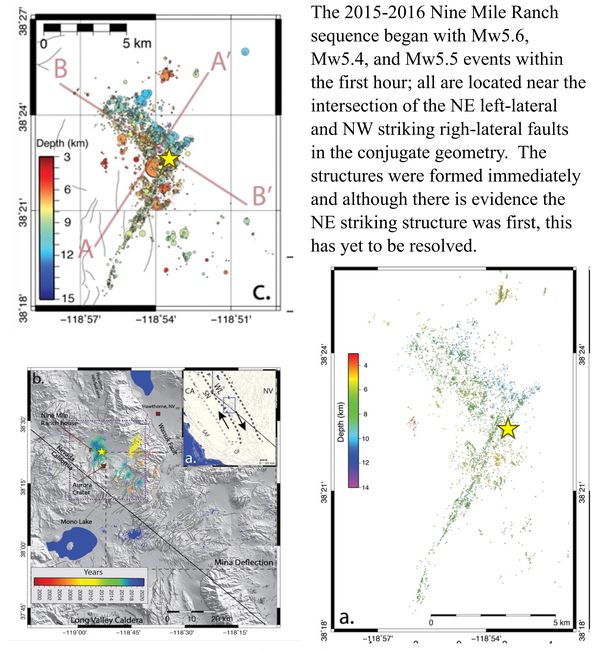
The 1984 Double Springs Flat sequence (Manshock: 9/12/1984:12:23 UTC - yellow star) initiated with the M5.8 NE striking left-lateral high angle mainshock. Several right-lateral offset high-angle M4 events on a NW striking structure began on 9/20, about 8 days after the mainshock. This structure intersects the mainshock fault plane near the the mainshock hypocenter. Activity extended to the south on addition intersecting conjugate fault sets; the sequence occurred in the left-step between the NS striking Antelope Valley and Genoa, down-to-the-east, range front faults.




***Ichinose, Smith, Anderson, 1988***

## *2016-2017 Nine Mile Ranch Sequence 3 M~ 5.5 Events - SW of Hawthorne, NV*

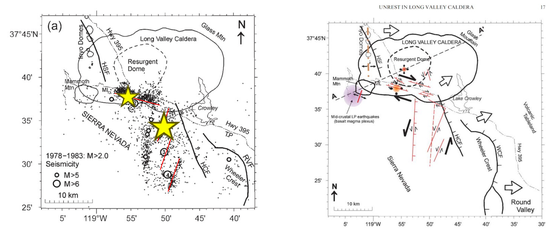
The 2015-2016 Nine Mile Ranch sequence began with Mw5.6, Mw5.4, and Mw5.5 events within the first hour; all are located near the intersection of the NE left-lateral and NW striking righ-lateral faults in the conjugate geometry. The structures were formed immediately and although there is evidence the NE striking structure was first, this has yet to be resolved.




***Hatch et al., 2020 - in prep.***

## *1980 Long Valley Sequence - Four M6 Events*

Four M6 earthquakes took place in the Long Valley Caldera and Sierra block south of the Caldera in May of 1980. Several of the events showed significant non-double couple components. Aftershocks generally align along high-angle N15E striking left-lateral structures south of the Caldera (3 of the M6 events) - the second M6 ruptured in NW striking right-lateral slip in the south Caldera area. The first event, 5/25/1989:16:33 - large yellow star) was followed at 16:49, 16 minutes later, by the south Caldera right-lateral offset event (smaller yellow star).



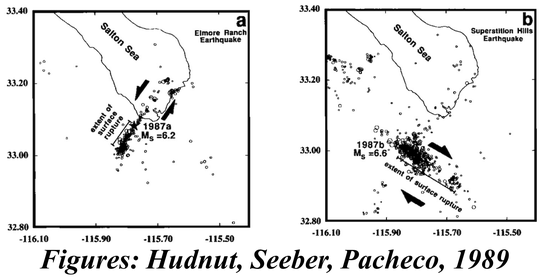




***Figures: Hill, 2006***

## *1987 M6.6 Superstition Hills, California*

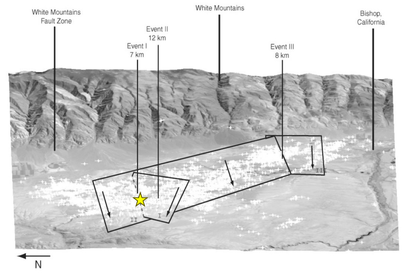
The 1987 Superstition Hills sequence initiated on a NE striking M6.2 left-lateral event on the Elmore Ranch fault (1987a figure below). It was followed 11.4 hours later by the NW striking M6.6 mainshock on the Superstition Hills fault (1987b figure below), defining the conjugate structure. Aftershock activity on the Elmore Ranch section diminished prior to the mainshock (Hudnut et al., 1988). Superstition Hills is often cited as a classic conjugate faulting sequence.

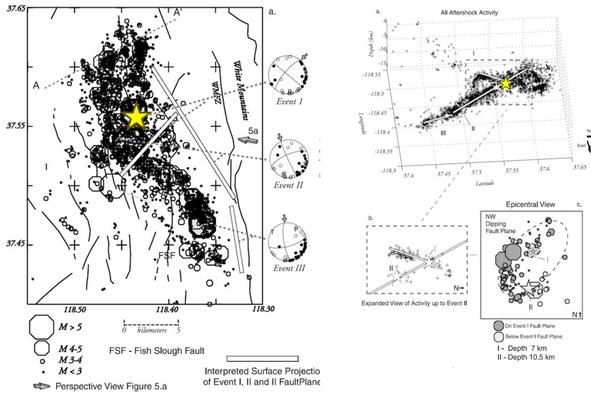



***Figures: Hudnut, Seeber, Pacheco, 1989***

## *1986 M6.3 Chalfant Sequence - East of Long Valley*

The 1986 Chalfant sequence initiated with an M5.9 NE striking left-lateral event (7/20/1986: 14:29 UTC - Event 1). The right-laterl NW striking Mw6.3 mainshock occurred 24 hours later (7/21/1986: 14:42 UTC - Event 2). Details of the structures can only be seen in perspective views of the earthquake relocations since the M5.9 foreshock and M6.3 mainshock fault planes dip to the NW and SE, respectively. The structures intersect near the hypocenter of the M5.9 foreshock. The perspective view of the interacting structures in the sequence can be seen in the topographic perspective view below; a view to the east into the White Mountains range front. The earthquake sequence occurred within the Volcanic Tablelands north of Bishop and east of Long Valley. The yellow star shows the location of the M5.9 foreshock in the figures below.

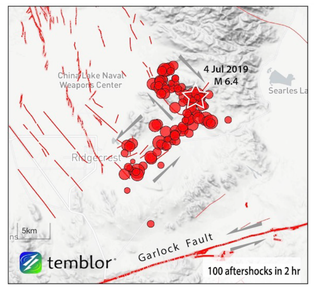


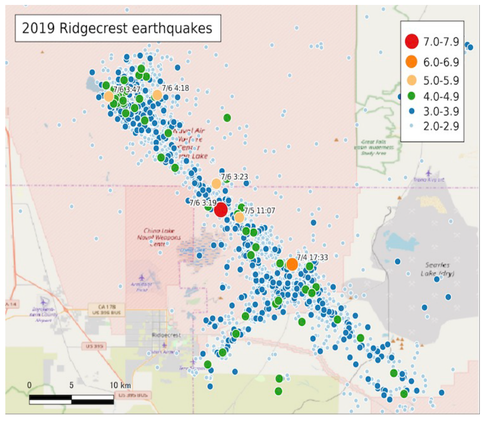

***Smith and Priestly, 2000***

## *2019 Ridgecrest, CA Sequence*

The primary moment release of the 2019 Ridgecrest sequence initiated with several NE and NW oriented sub-events associated with the initial Mw6.4 foreshock (7/4/2019:17:33 UTC). This set of sub-events, fault fracture mesh, preceded the NW striking right-lateral Mw7.1 mainshock (7/62019:03:19 UTC) by 34 hours. Lomax, 2020, and Ross et al., 2020, have illustrated the complexity in the early Ridgecrest sequence in high-precision relocations; the NE-SW striking left-lateral sub-event in the foreshock set extends approximately 18 km.




***Temblor, http://doi.org/10.32858/temblor.039***




***https://en.wikipedia.org/wiki/2019_Ridgecrest_earthquakes***

## *Summary and Conclusions*

We provide simple observations of conjugate strike-slip faulting in moderate sized earthquakes sequences in the transtensional Walker Lane region of the western US since modern digital seismic recording generally began in mid-1980s. The details of moderate sequences require a significant catalog of aftershock data and application of some type of relocation routines. Remarkable images of recent earthquake sequences (e.g., Lomax, 2020, and Ross et. al, 2020 - Ridgecrest) demonstrate the value of high-quality data and modern processing applications.

Many of these moderate size earthquake sequences in western US transtentional tectonic environments evolve into conjugate geometries with an initial NE striking left-lateral moderate slip event. The overall strain field is driven by plate boundary motion under a generally NW to WNW oriented T-axis. This evolution into conjugate geometry, left-lateral to right-lateral, is surely the case for the 1984 M5.9 Round Valley, 1986 M6.3 Chalfant, M5.9 Double Springs Flat, and 2016 M5.6 Nine Mile Ranch sequences in the central Walker Lane region. It may be case in the initial two M6 events of the 1980 Mammoth Lakes sequence in the complex fault fracture systems associated with the Long Valley Caldera. Although the Superstition Hills sequence is outside of the Walker Lane proper it also progressed into a conjugate geometry of moderate earthquakes, left-lateral first, in the transtensional stress regime in the Salton Sea area (Superstition Hills is noted for the conjugate geometry and also includes an initial left-lateral moderate event). The fault fracture mesh imaged in the 2019 Ridgecrest sequence is more complex than other Walker Lane sequences noted here. The Ridgecrest data quality is unprecedented and other less well recorded sequences may indeed have much more complexity. The complexities imaged in the Ridgecrest sequence are similar to structures imaged in the Long Valley volcanic area (Prejean et al. 2002; Shelly et al., 2011).

We also note that the moderate sequences in the left-lateral structure domain of the Mina Deflection in the central Walker Lane tend not to show this particular behavior following initial moderate to large left-lateral events (e.g., 2004 M5s Adobe Hills, 2020, and the recent 2020 M6.5 Monte Cristo Range earthquake). There are, however, prominent off-fault and cross-fault structures in the aftershock distributions.

One interpretation, possible mechanism, for initial left-lateral faulting in conjugate geometries is that the T-axis is at a high-angle to an initial rupture and that these sequences are triggered by lowering the normal stresses in preferably oriented structures. Triggering of the right-lateral systems may progress accordingly by reducing normal stresses on these structures, as has been proposed in other studies.


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