Imaging damage zones and fault growth processes with high-precision relocations of earthquake sequences

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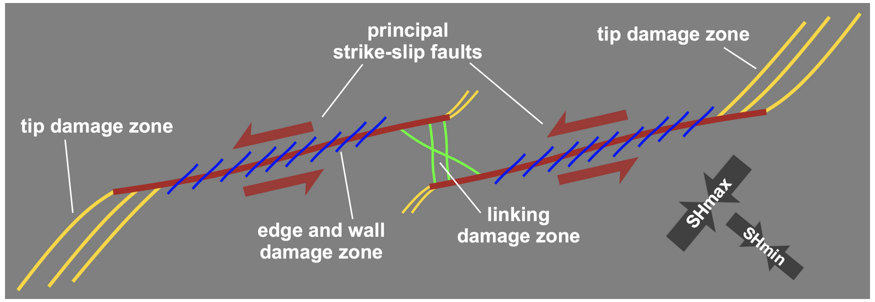
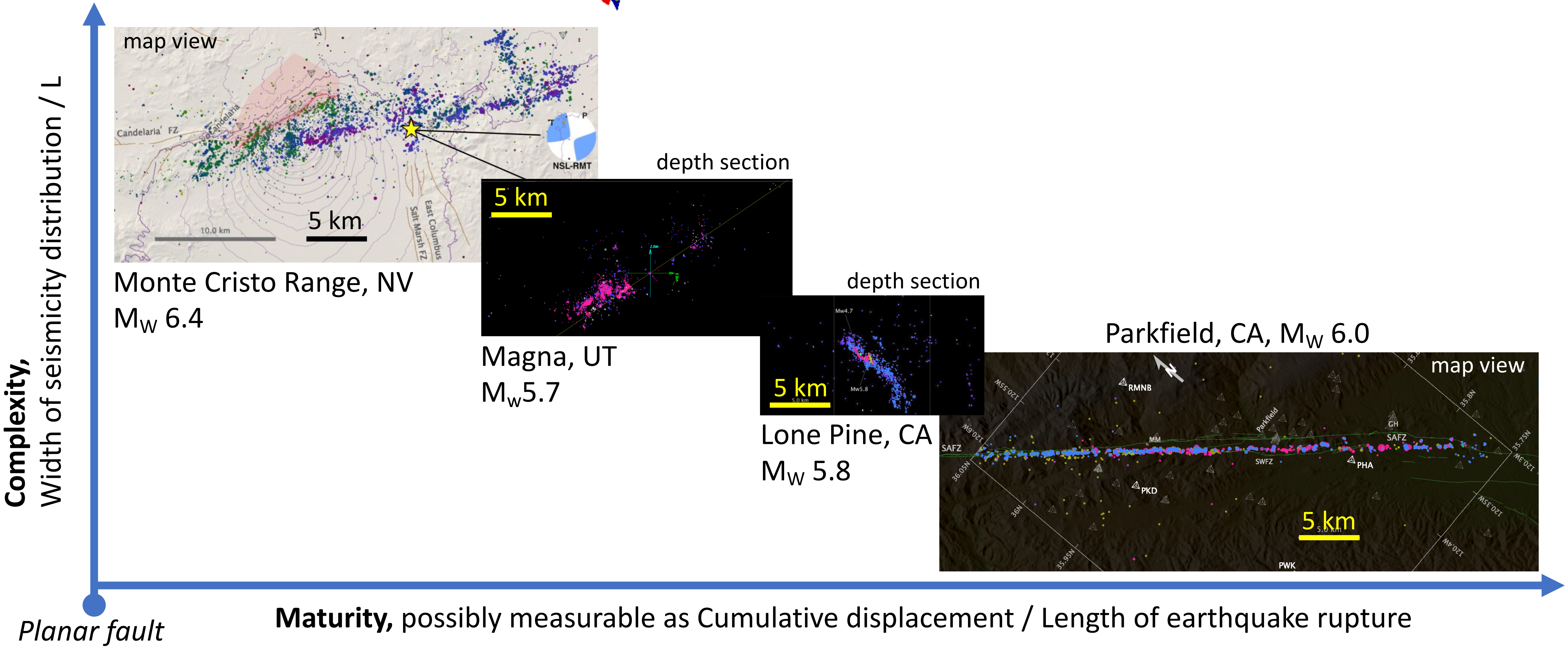
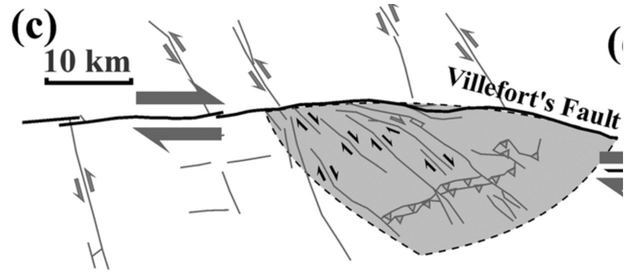


Complete shear crack system



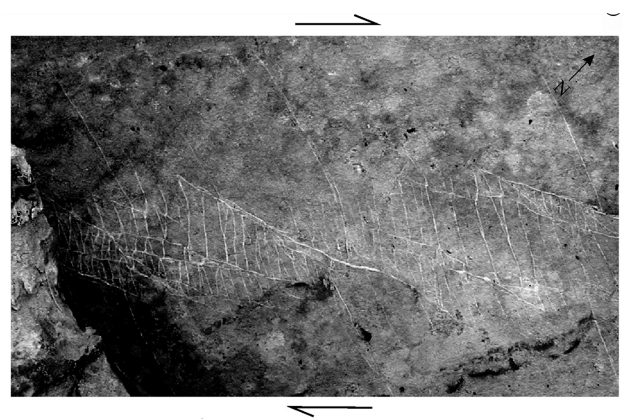
Elements of a shear crack system



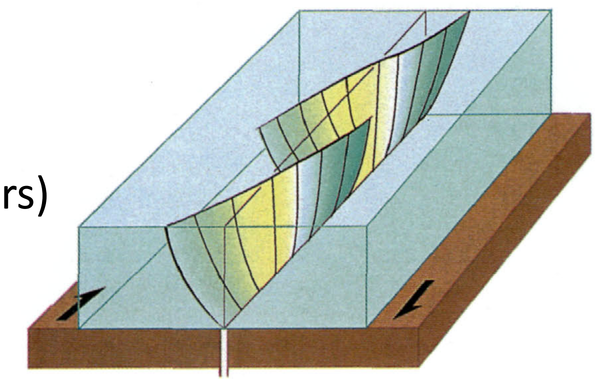
Tip *(Granier, 1985; Kim et al., 2004)*

- Tip splays (e.g. horse tail)
- Edge splays (e.g. R1 Riedel shears)
- Linking fractures (e.g. R2 and P shears)
- Wall damage zone (halo zone)

Halo *(Faulkner and Mitchell, 2011)*

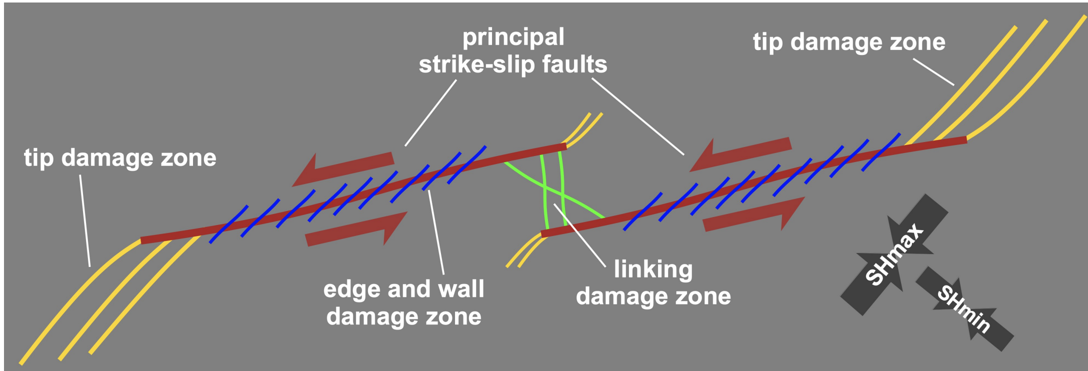


Linking *(Katz et al., 2004)*

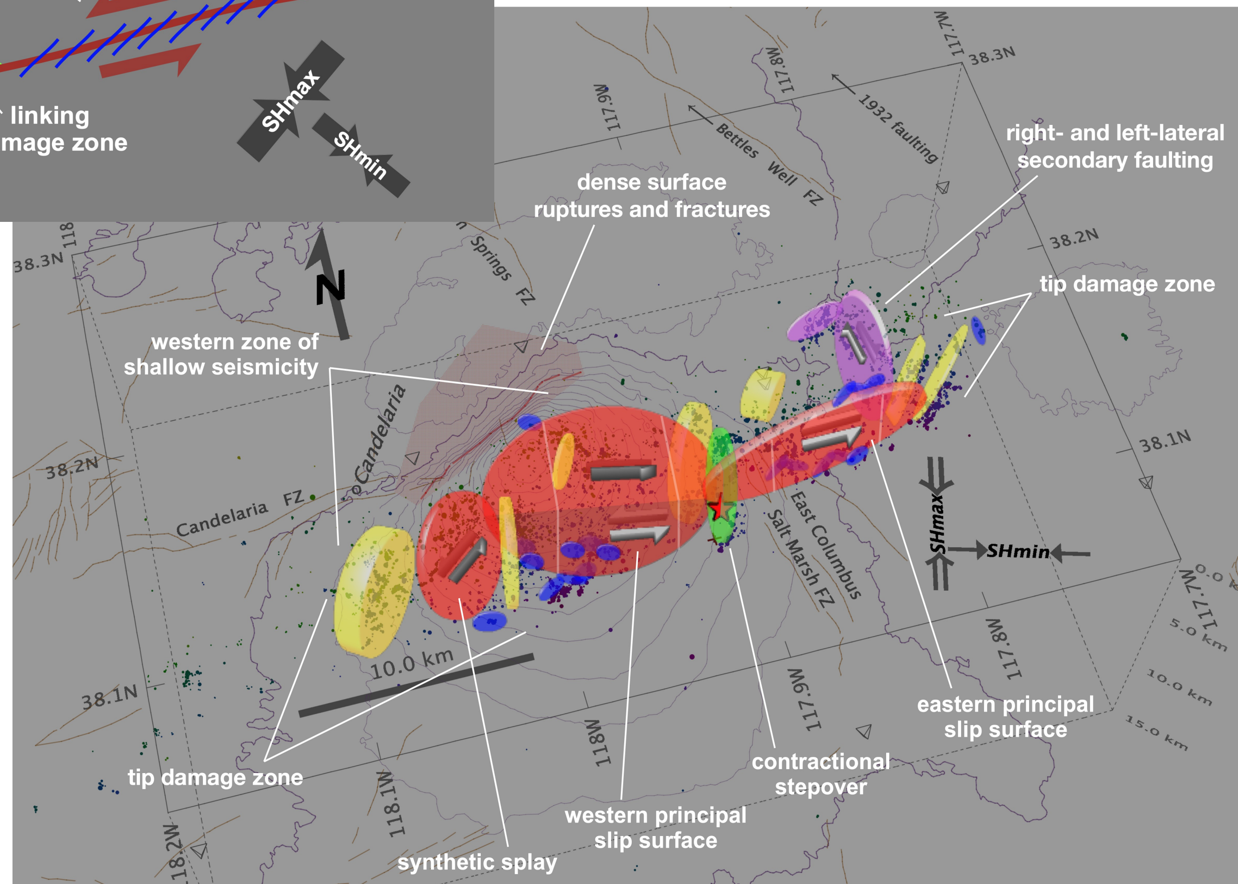


Edge *(Richard et al., 1995)*

A complete shear crack system



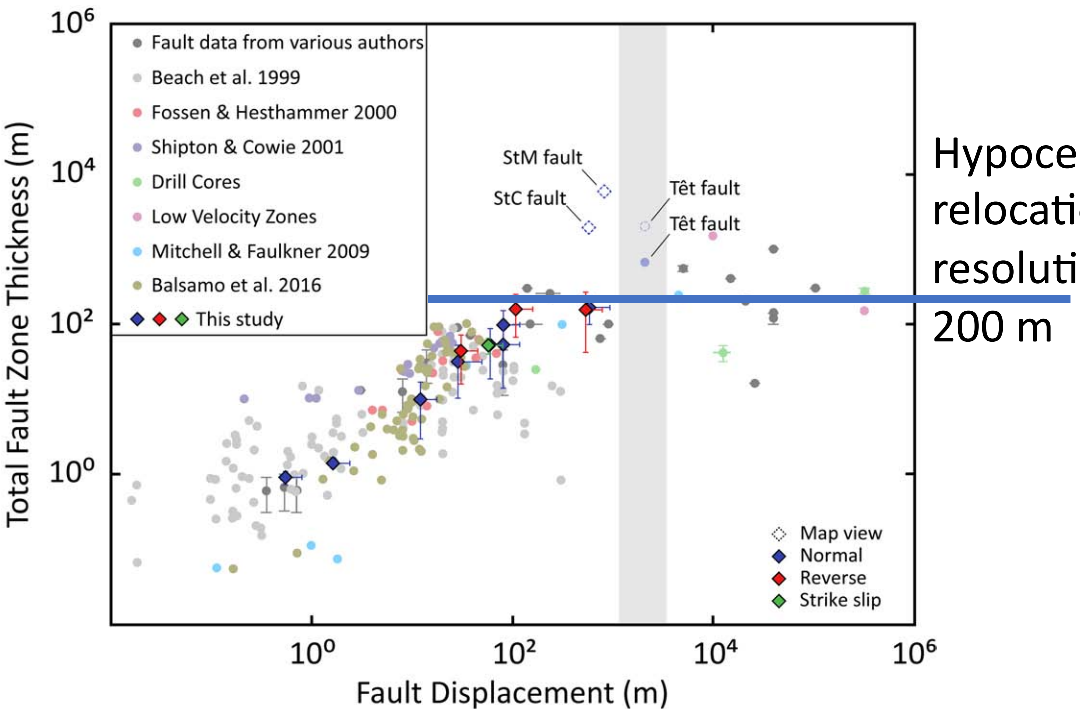
2020 Monte Cristo, NV sequence, M_w 6.5
(Lomax, 2021, Eartharxiv preprint)



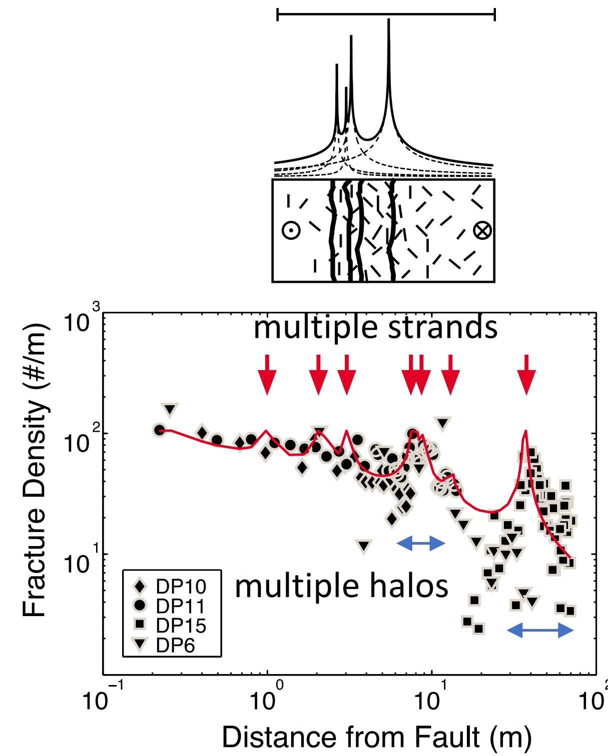
- Can high resolution hypocenter distributions be interpreted as damage distribution ?
- Is the structural evolution of a damage zone determined by scale and earthquake history ?

Fault damage zone scaling

- Field observations indicate that damage zones scale with displacement up to ≈1 km
- Faults with displacements larger that 100 m typically have complex damage zones comprising several strands with their own fracture « halo »
- Structures within the damage zones of the larger faults may be resolved with high resolution relocation methods



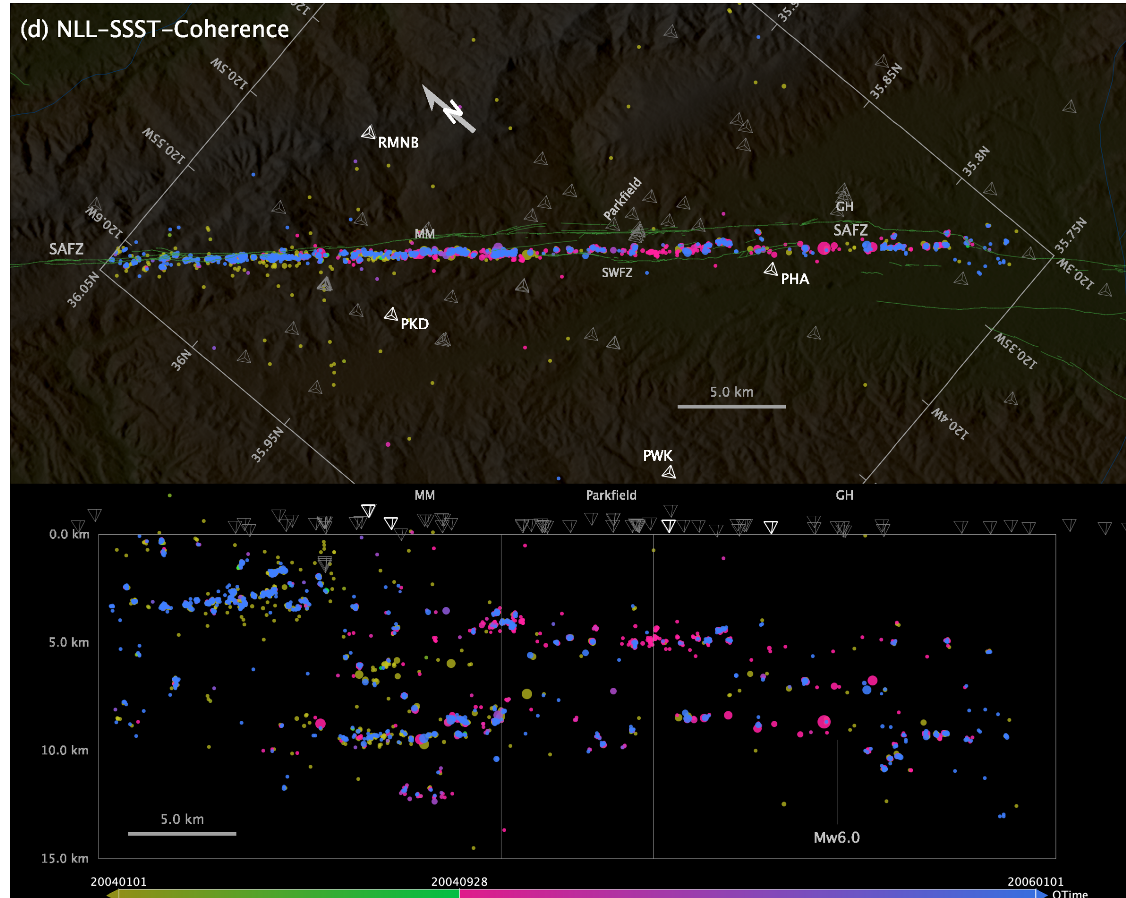
Hypocenter relocation resolution 200 m



(Mayolle et al., 2019; Savage and Brodsky, 2011)

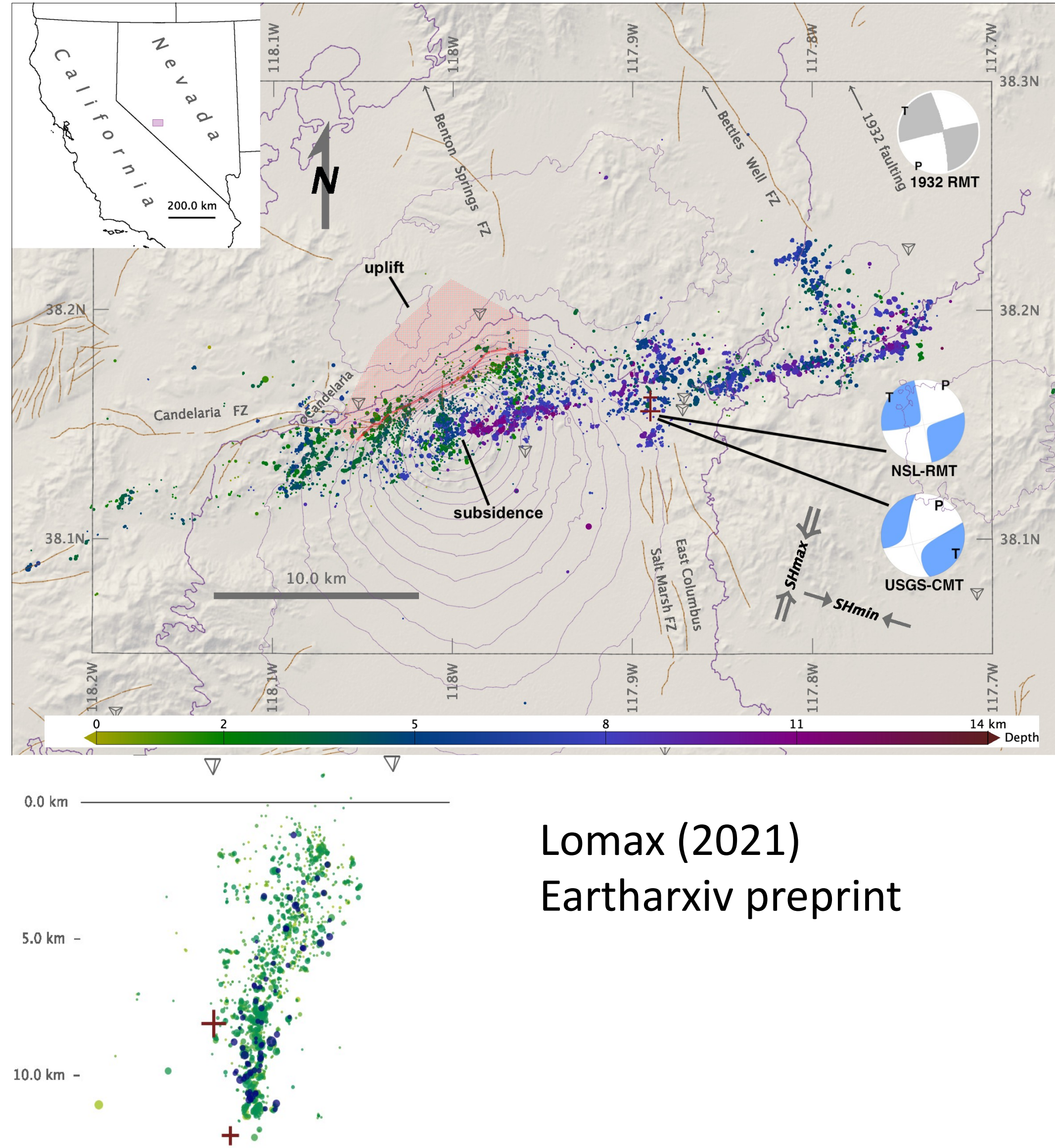
2004 Parkfield California sequence
M_w6.0, strike-slip

- Hypocenters focussed within a few hundreds of m of the principal slipping plane
- Mature fault zone with >150 km displacement
- Narrower hypocenter zone than suggested by the average damage zone vs displacement scaling relationship



2020 Monte Cristo, NV sequence
M_w 6.5, strike-slip

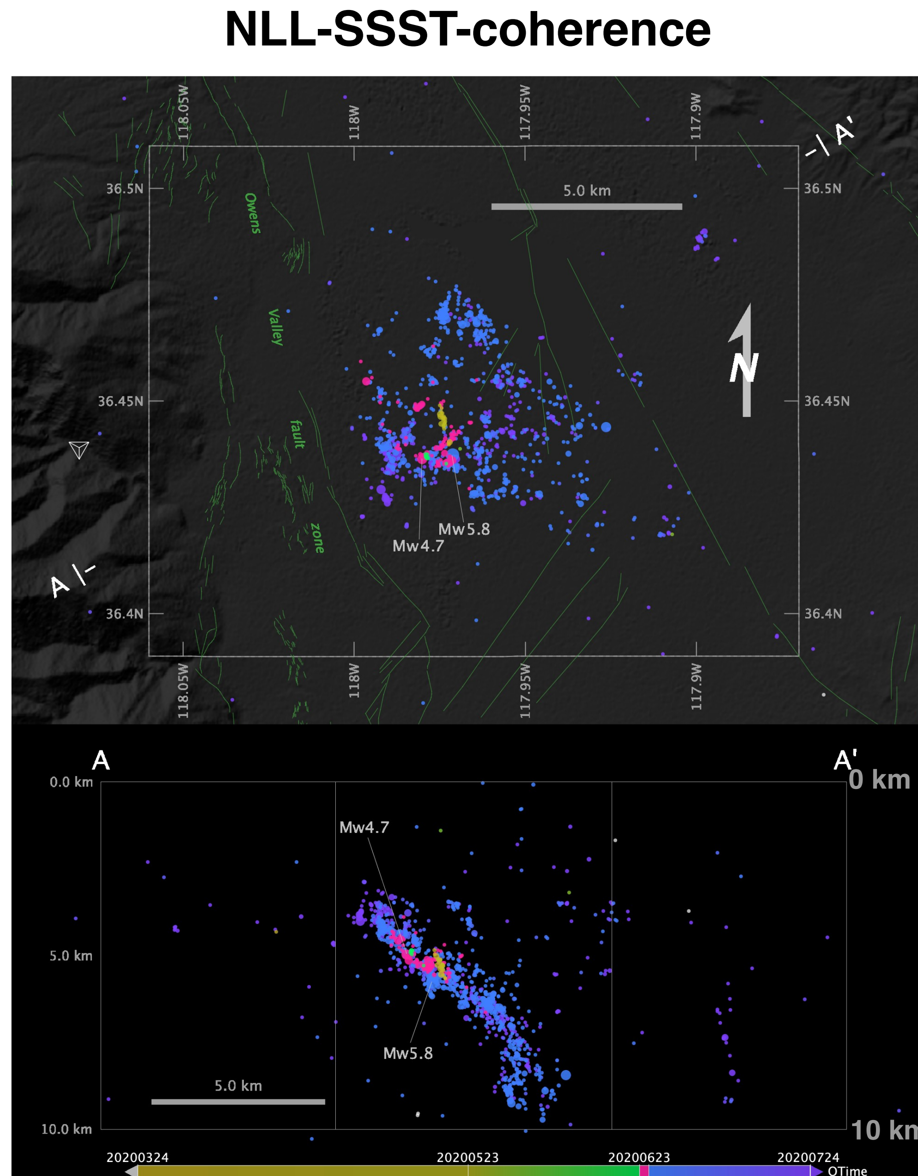
- Hypocenters spread in 5 km wide zone
- Fault does not have a continuous expression on the surface
- Hypocenters are more focussed at depth, around two main en-echellon segments
- Zone of aftershocks broadens toward the surface



Lomax (2021)
Eartharxiv preprint

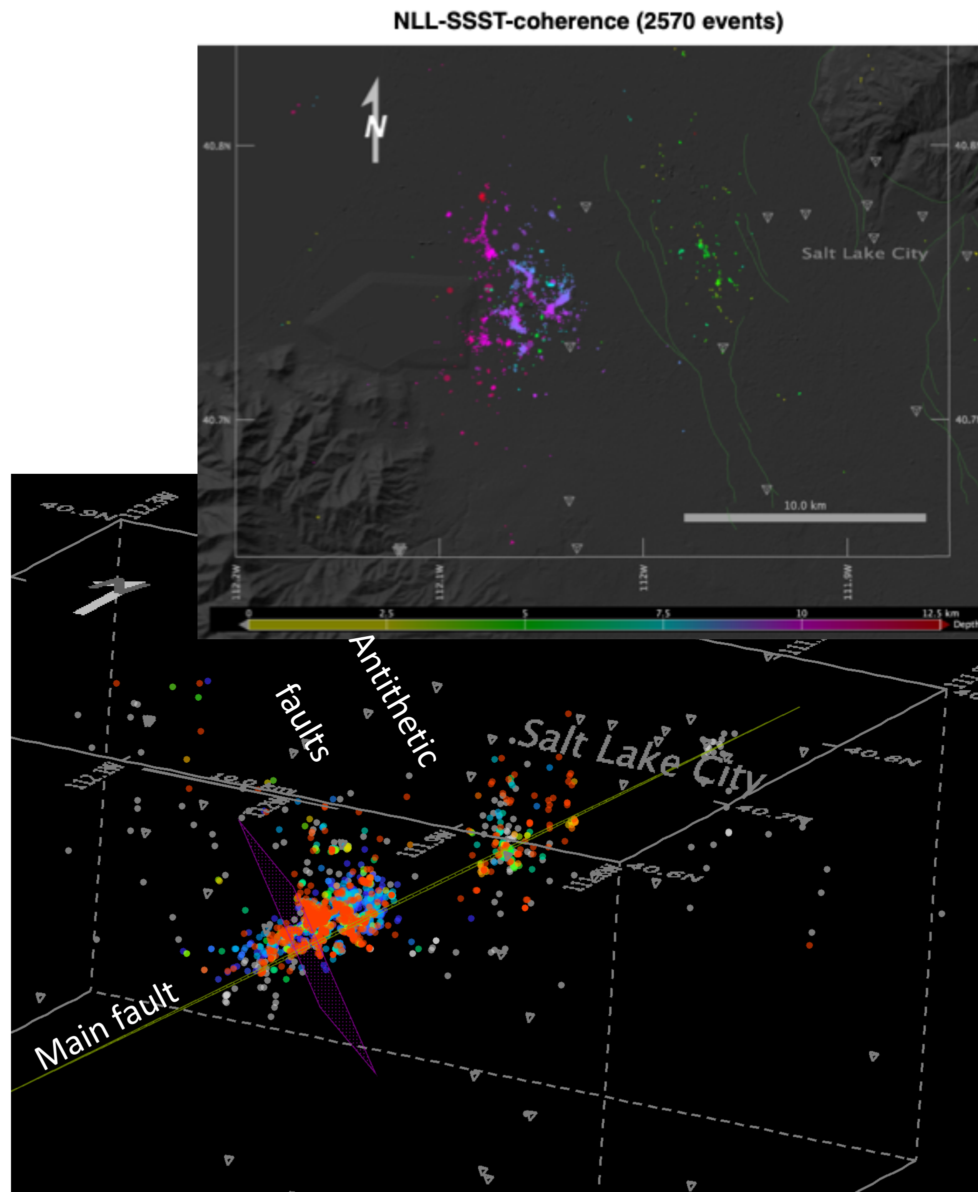
2020 Lone Pine, CA sequence M_w 5.8, normal

- Most hypocenters are located close to a bent surface that may be interpreted as a unique slip surface or as a series of steeply dipping, sub-parallel faults
- Hypocenters on map define a boundary on this surface, presumably the edge of slip zones, combining a foreshock, the main shock and one large aftershock

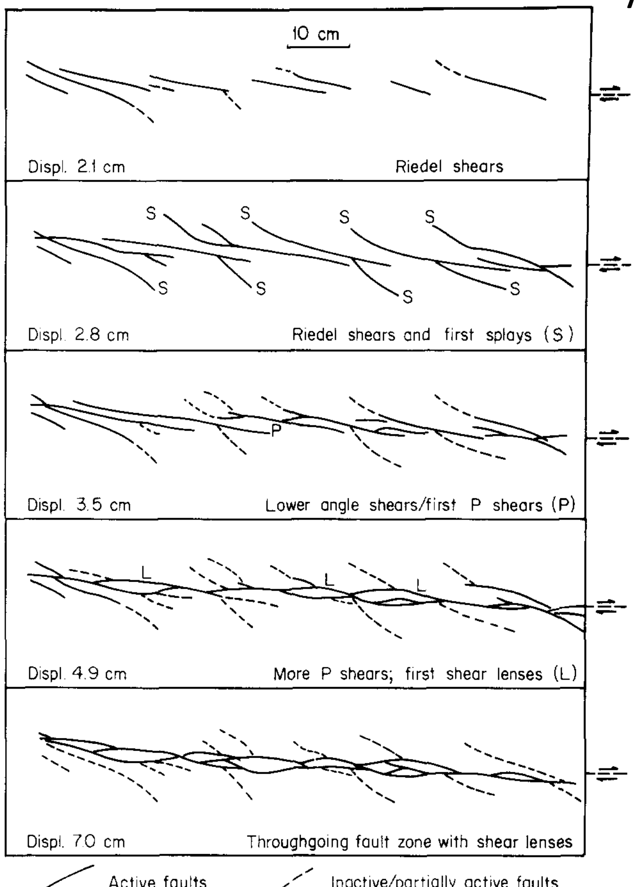


2020 Magna, UT sequence M_w 5.7, normal

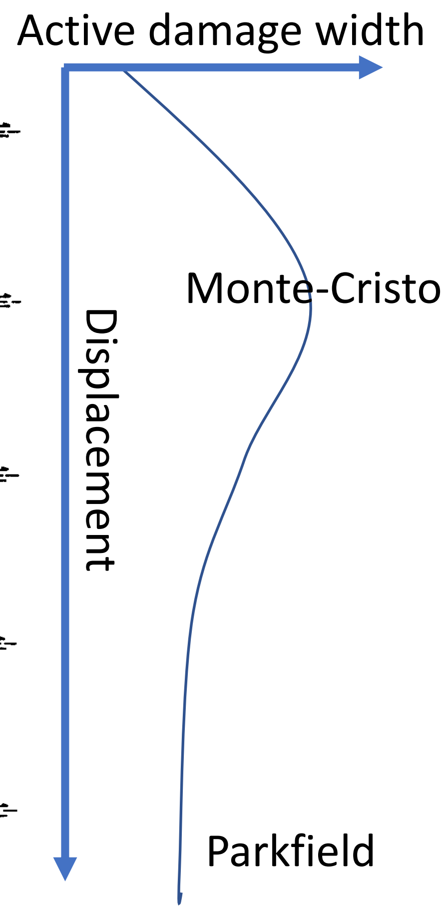
- Main fault plane is a W-dipping normal fault
- Aftershocks forms a complex pattern updip of the hypocenter, imaging antithetic faults in the hanging wall and their intersections with the main fault
- This seismicity and a shallower up-dip cluster of aftershock seismicity correspond to clusters of background seismicity



Scaling depends on fault maturity

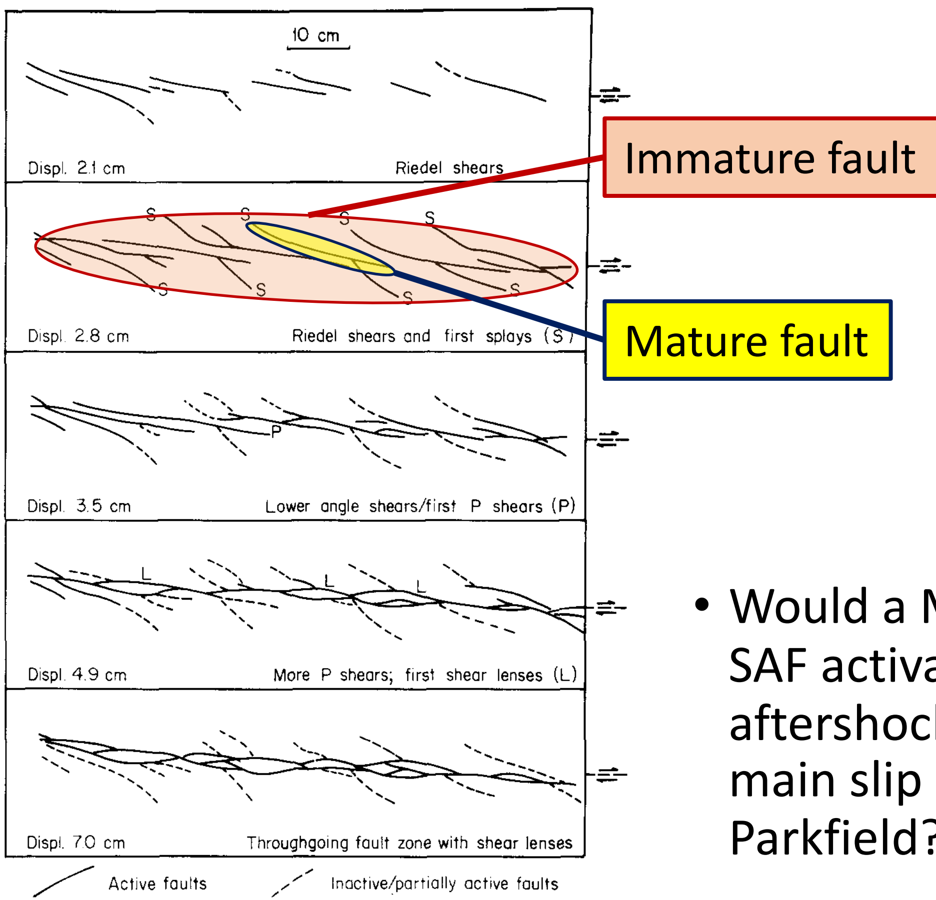


Naylor et al. (1986)



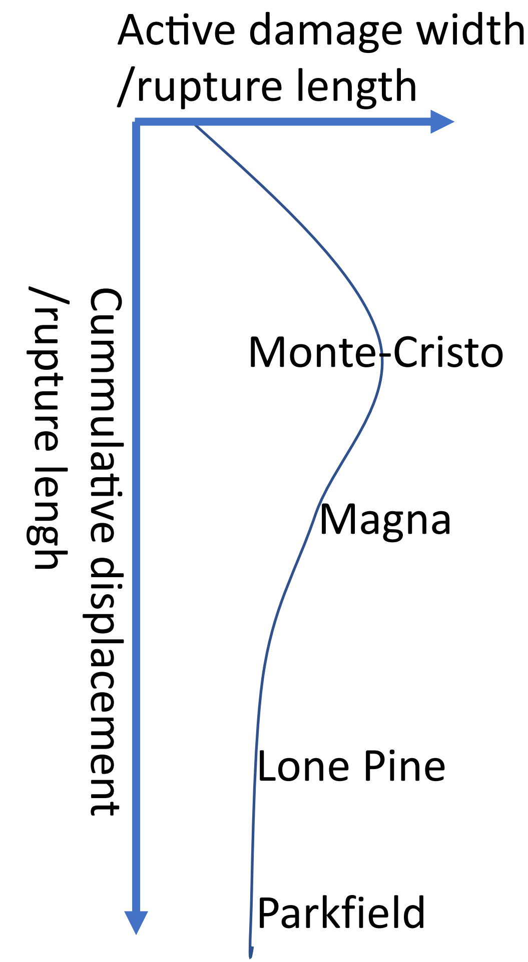
- In analog experiments (edge dislocation case), the width of shear zones peaks just before the formation of connecting faults
- Shear localization along a fault implies narrowing of the zone of active damage with time

Fault maturity at a given time depends on scale



Naylor et al. (1986)

- Would a M8 on the SAF activate a lot more aftershocks off the main slip plane than Parkfield?



Conclusions

- Seismicity distribution during an earthquake sequence reveals the geometrical complexity of the activated fault system.
- Geometrical complexity is highly variable depending on case, and may relate to the « maturity » of the fault system.
- Interpreting aftershock distribution as damage suggests a distinction should be made between
  - Near fault damage, which may persists along mature faults in relation with rupture related stress (dynamic and rupture tips) and asperity abrasion
  - Off fault damage related to various secondary structures, the number and size of which presumably peak during fault growth
- Damage zones observed on the field may integrate the whole history of fault growth and slip, complicating their understanding in term of scaling relationships