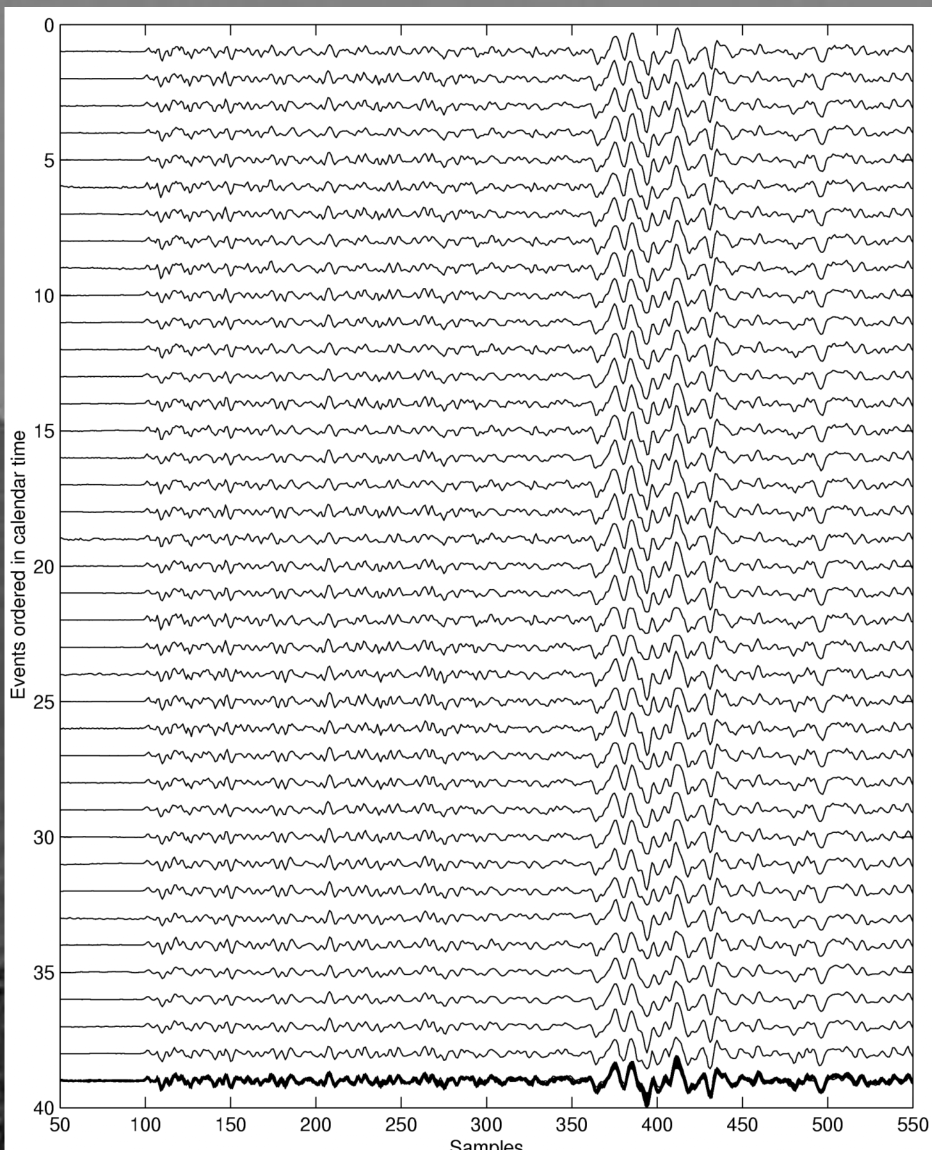
Evidence of Nonlinear Strong Ground Motion from Repeating Microearthquakes

Justin Rubinstein and Greg Beroza

UJNR Meeting, Asilomar

October 13, 2004

Repeating Earthquakes



Very repetitive!

(37 in this sequence)

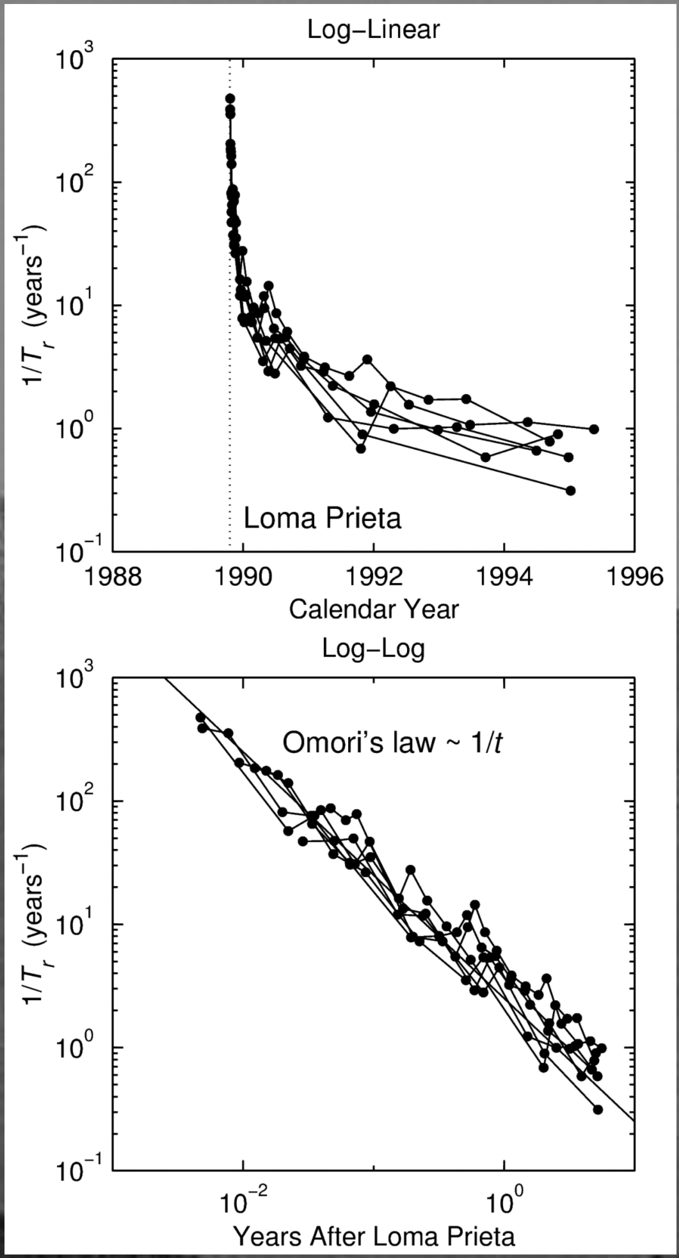
Common source and path ---- ideal for monitoring velocity changes (*Poupinet and Ellsworth*, 1984)

Recurrence intervals

Follow Omori type (1/*t*) decay.

Consistent with velocity strengthening friction.

Ideal for monitoring immediate post-seismic period.

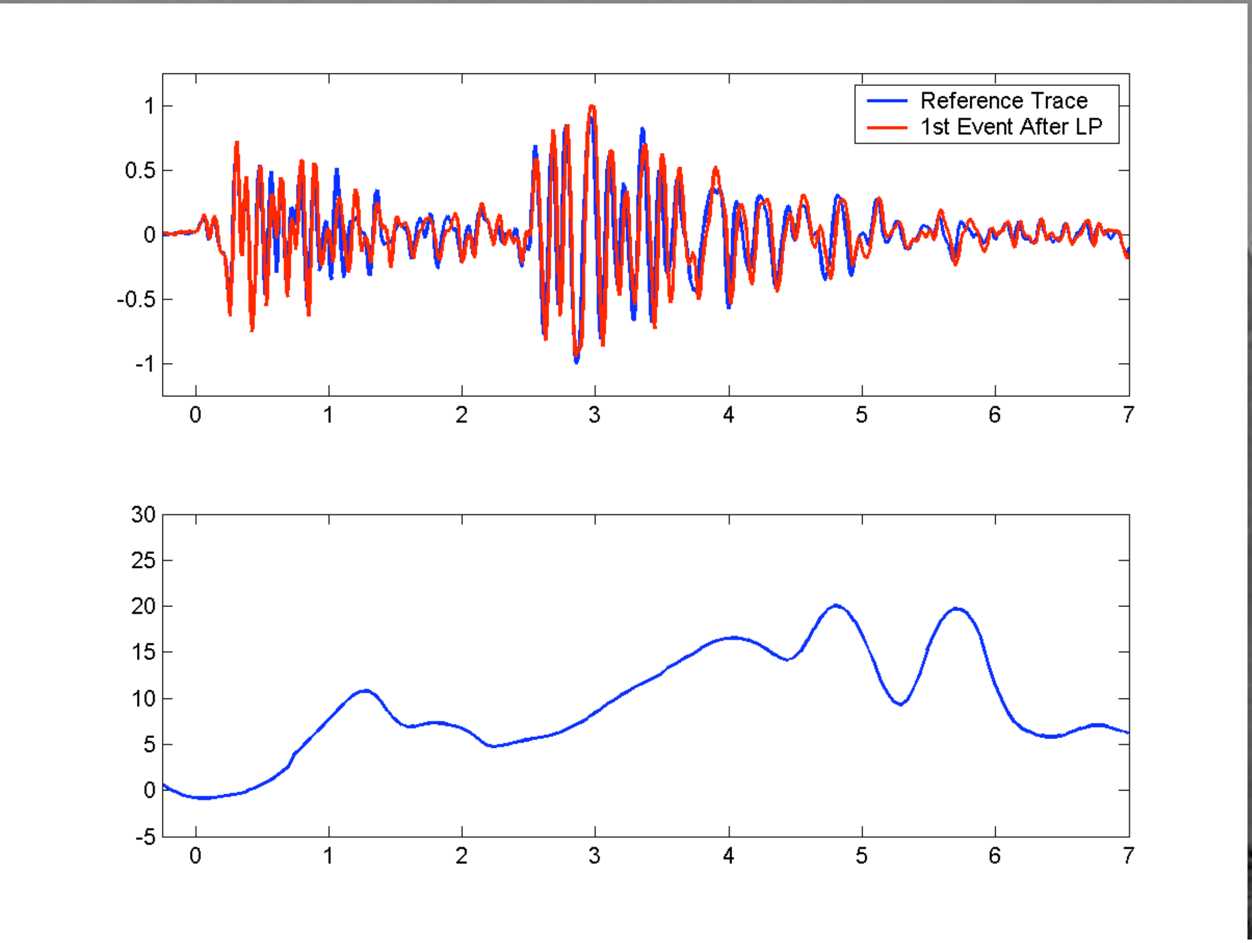


Time Measurement

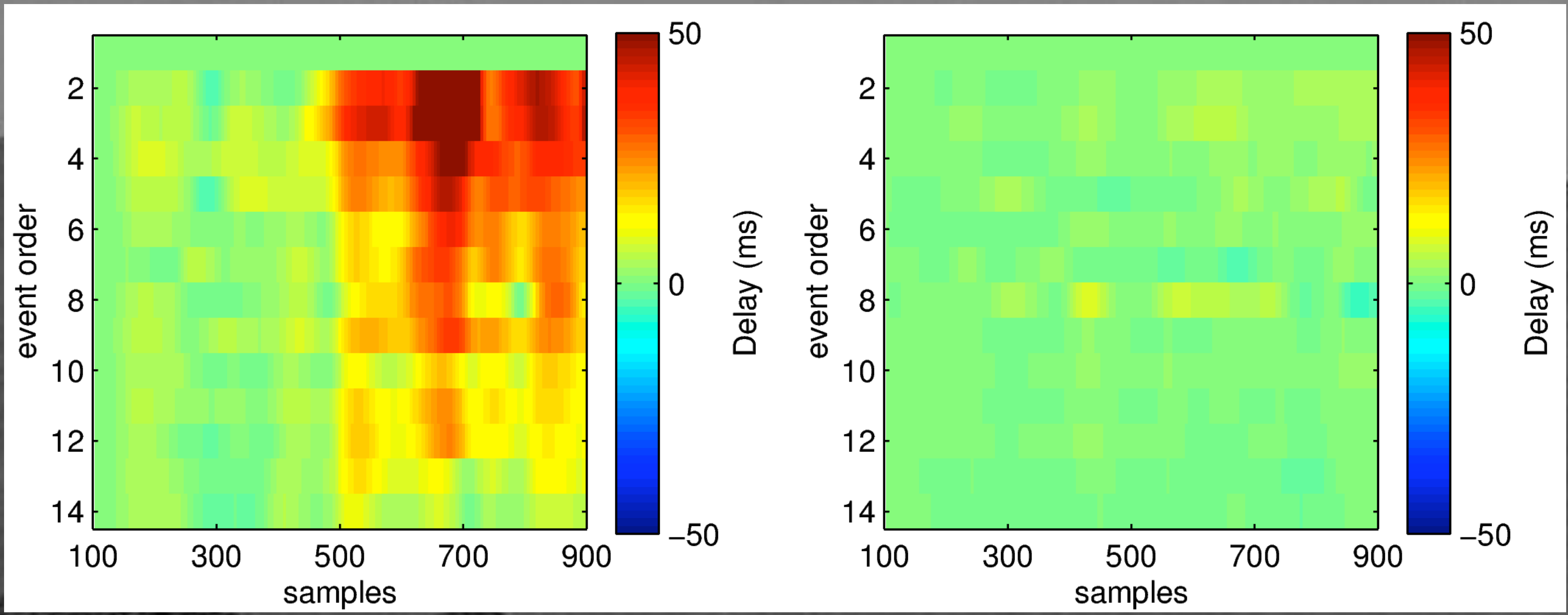
- Align on P arrival to sub-sample precision
- Apply moving window cross-correlation analysis

--1st event is reference

--128 sample window



Color Representation of Delay vs. Time in the Seismogram



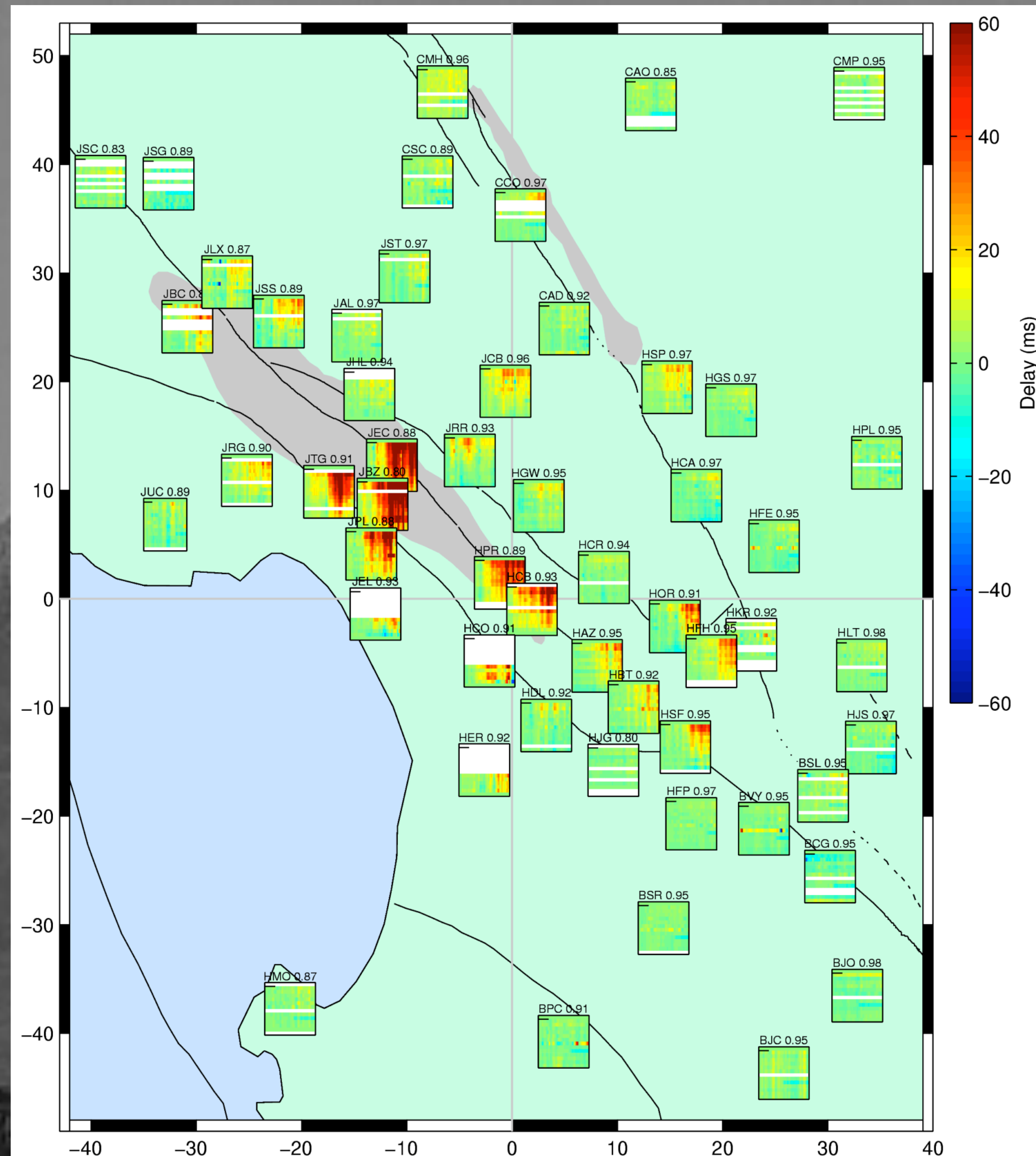
Results shown for 14 events.

Changes following M 6.9 Loma Prieta.

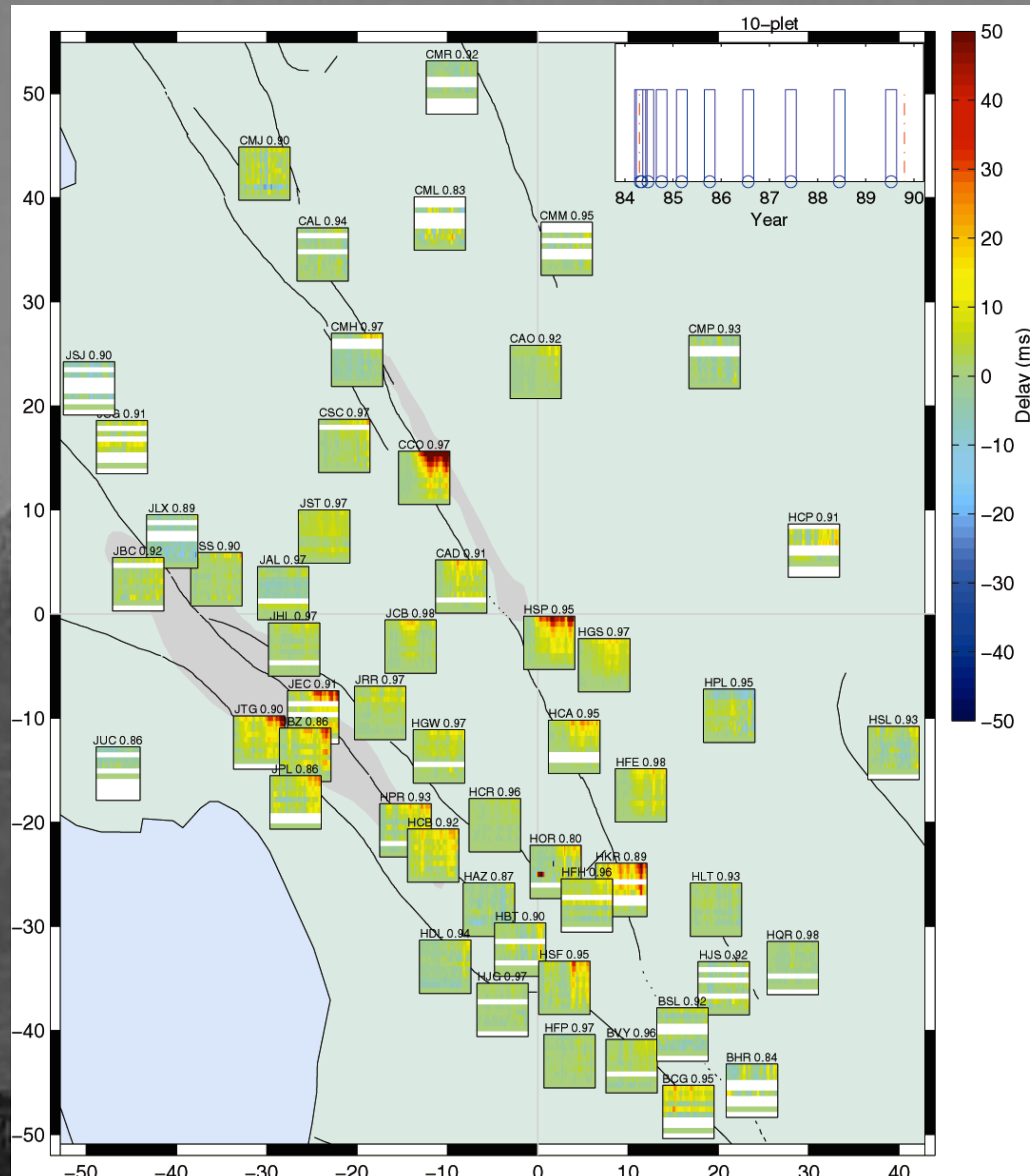
Change is always positive.

Concentrated near mainshock.

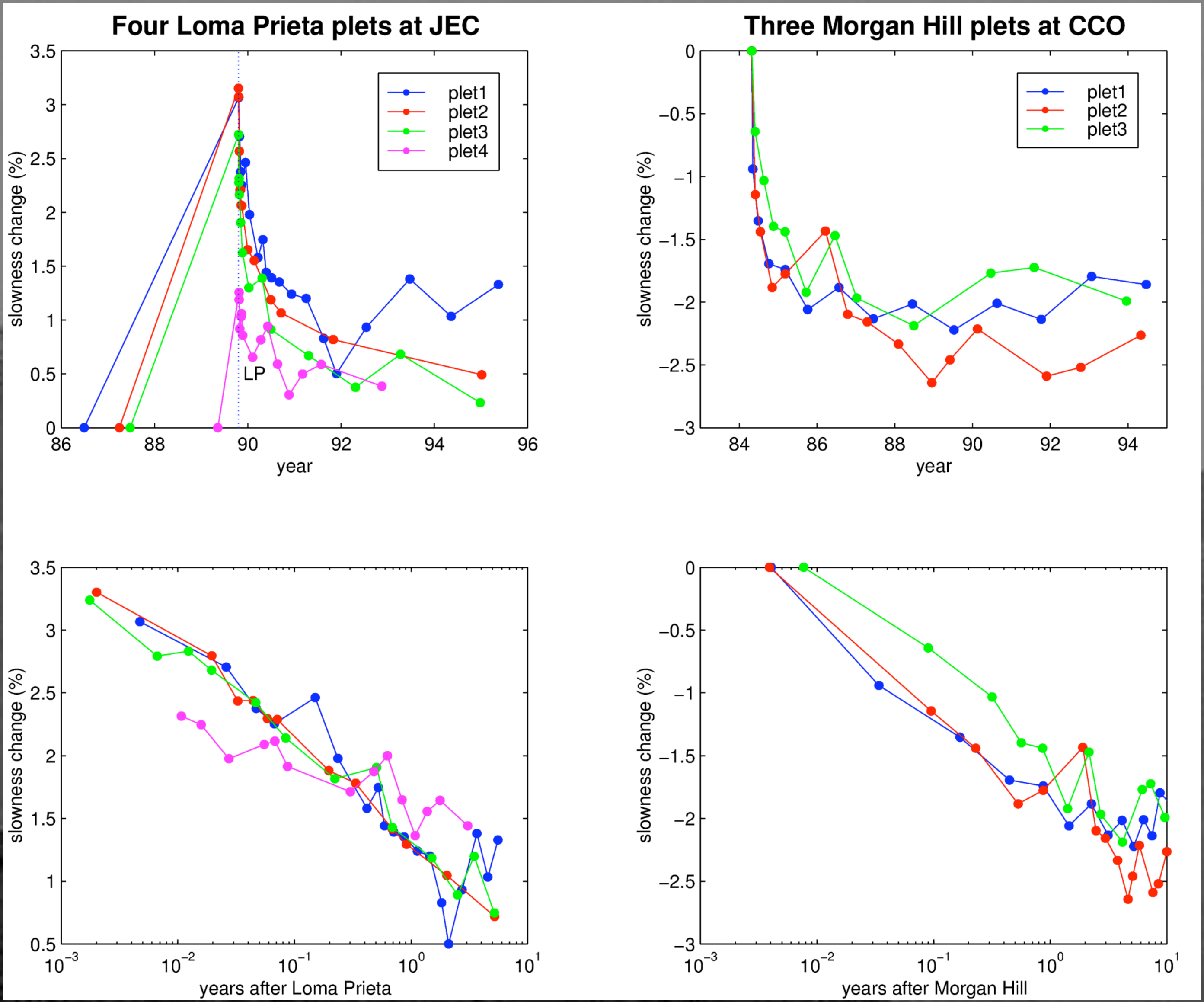
Decays with time.



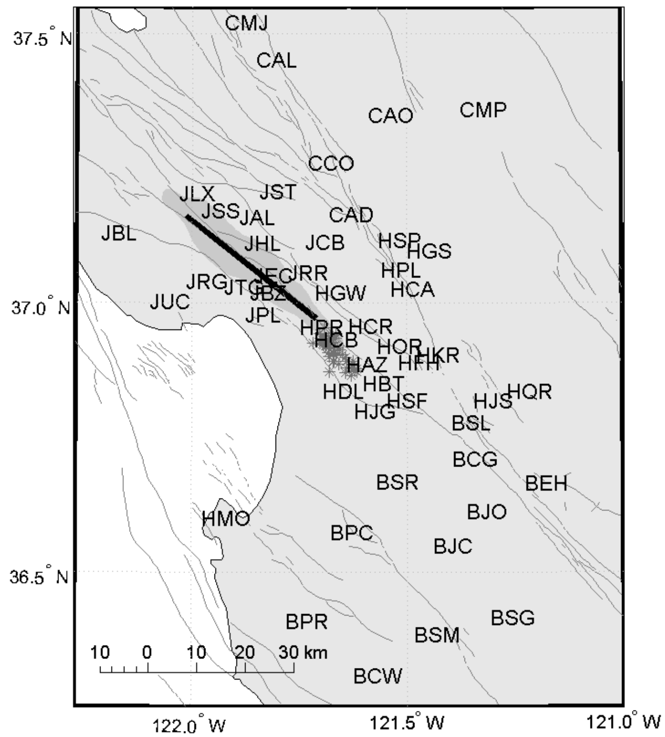
Similar behavior after M 6.2 Morgan Hill earthquake.

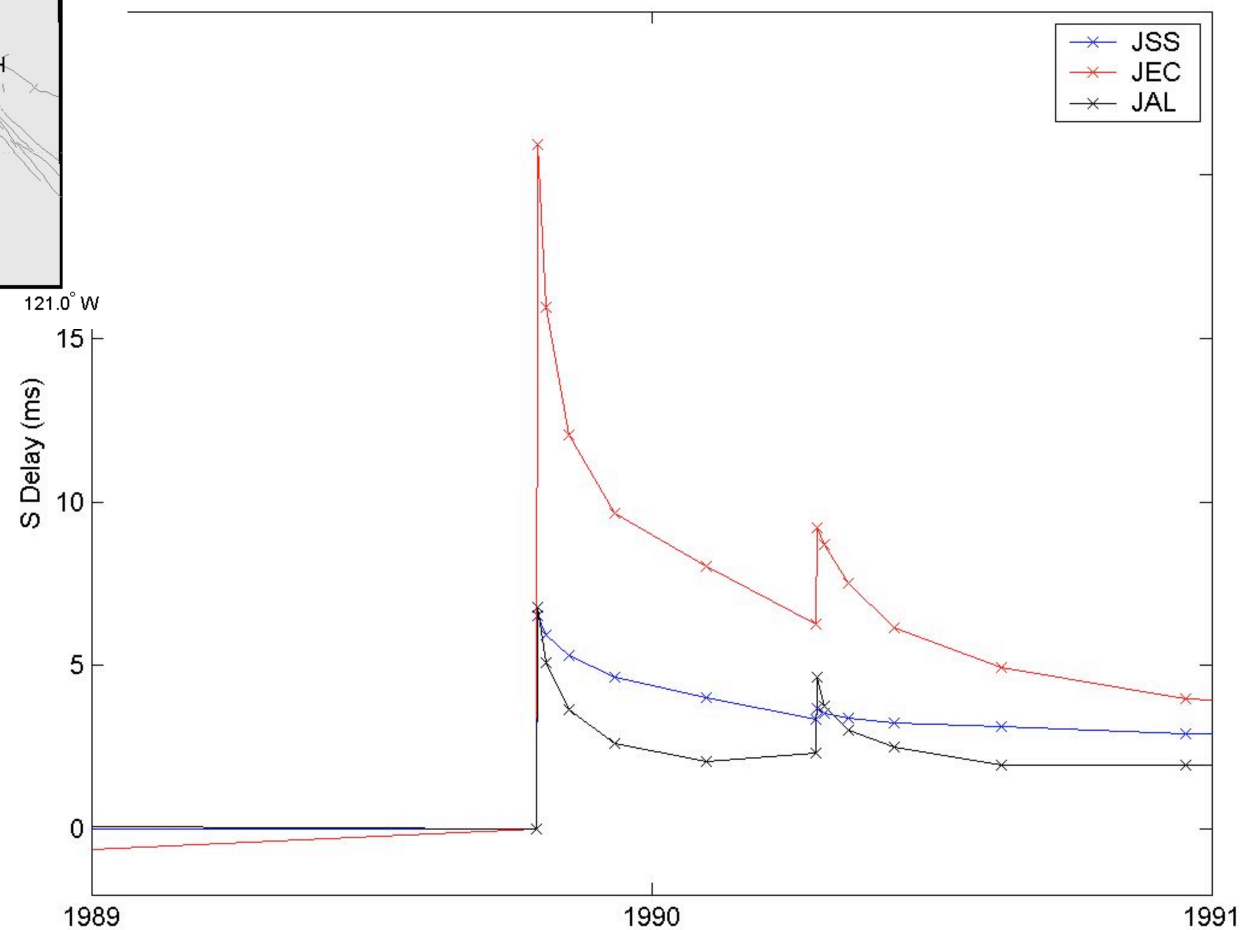


Time Dependence: Logarithmic Decay

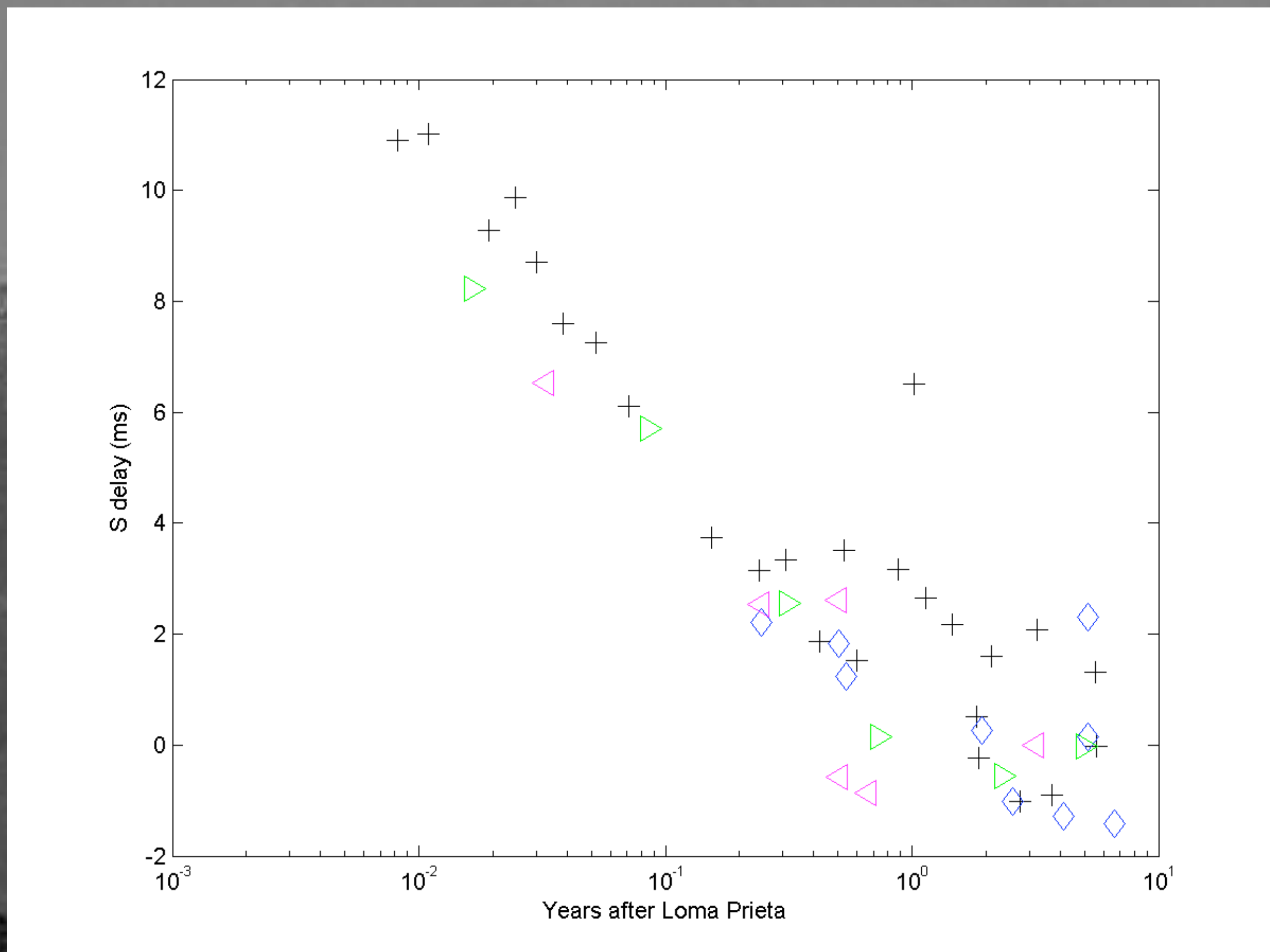


Not proportional to propagation path through mainshock region.



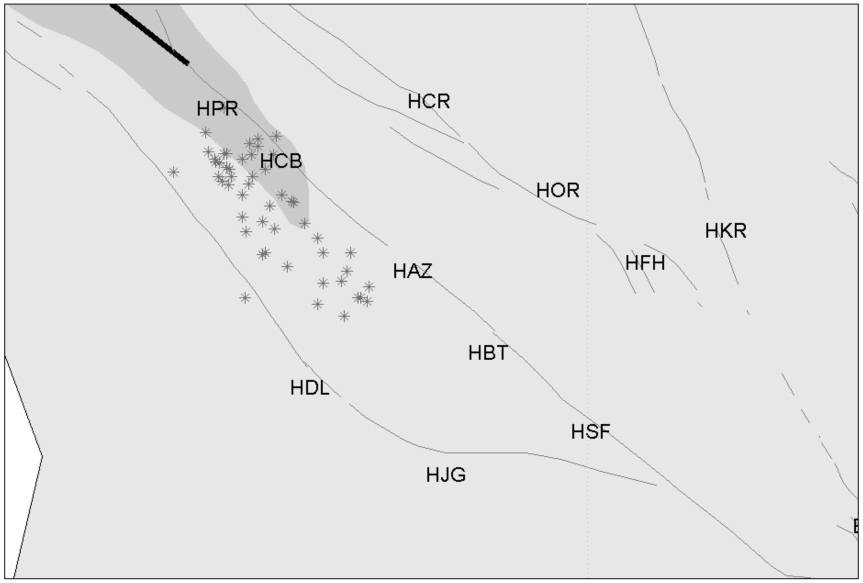


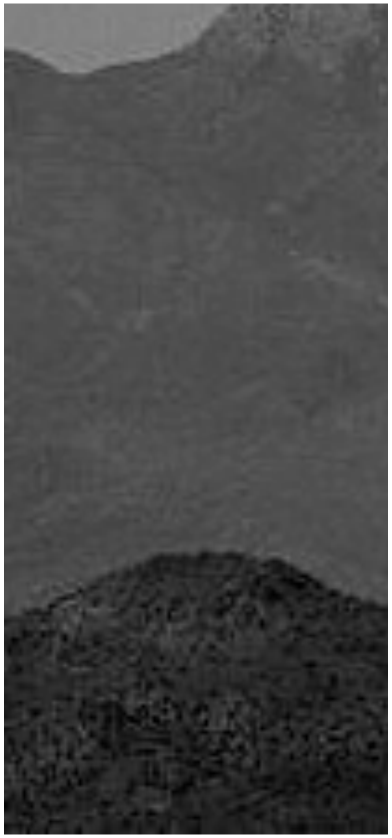
Different Sources Show Similar Effects

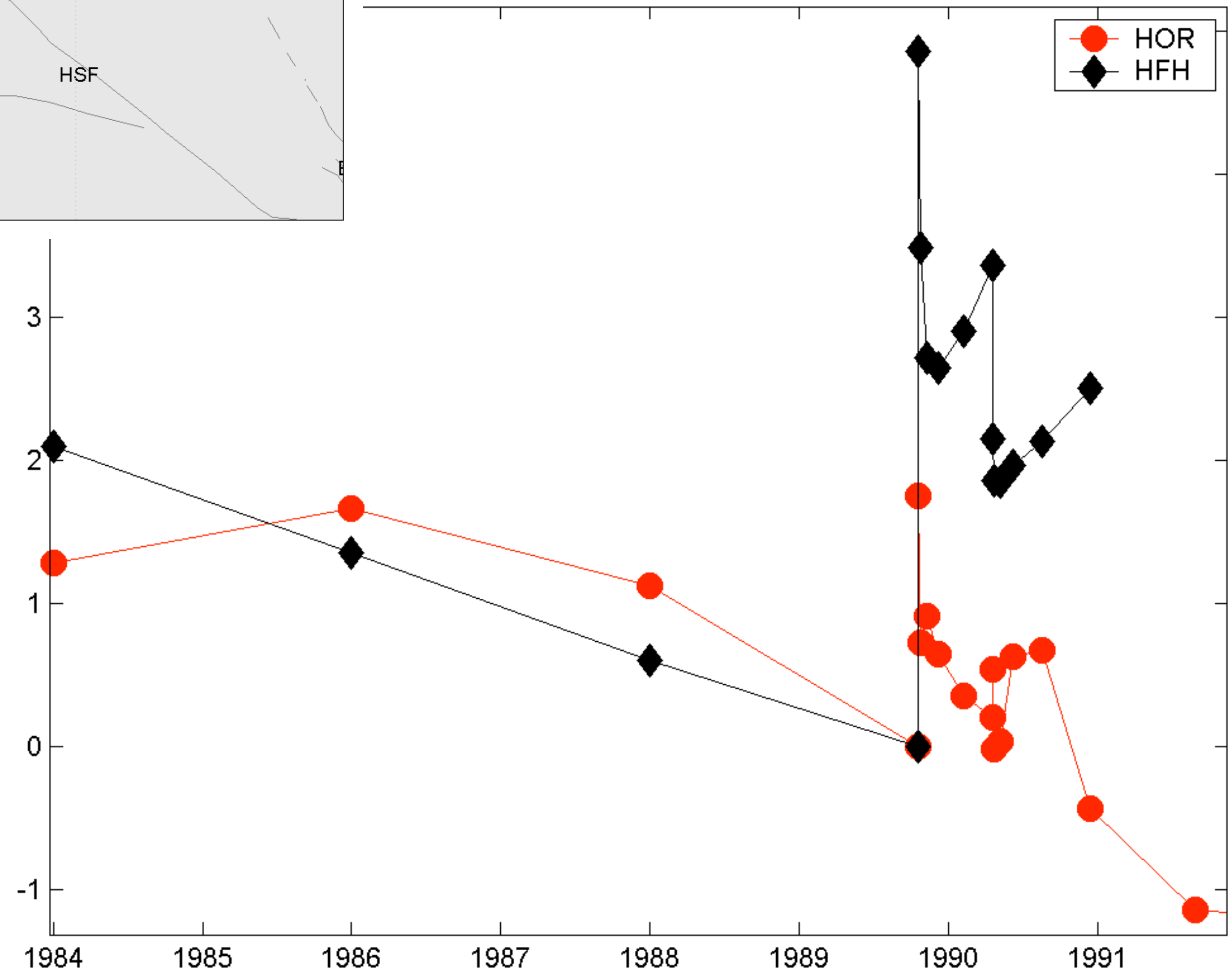


Represent with Time-Dependent Station Delay

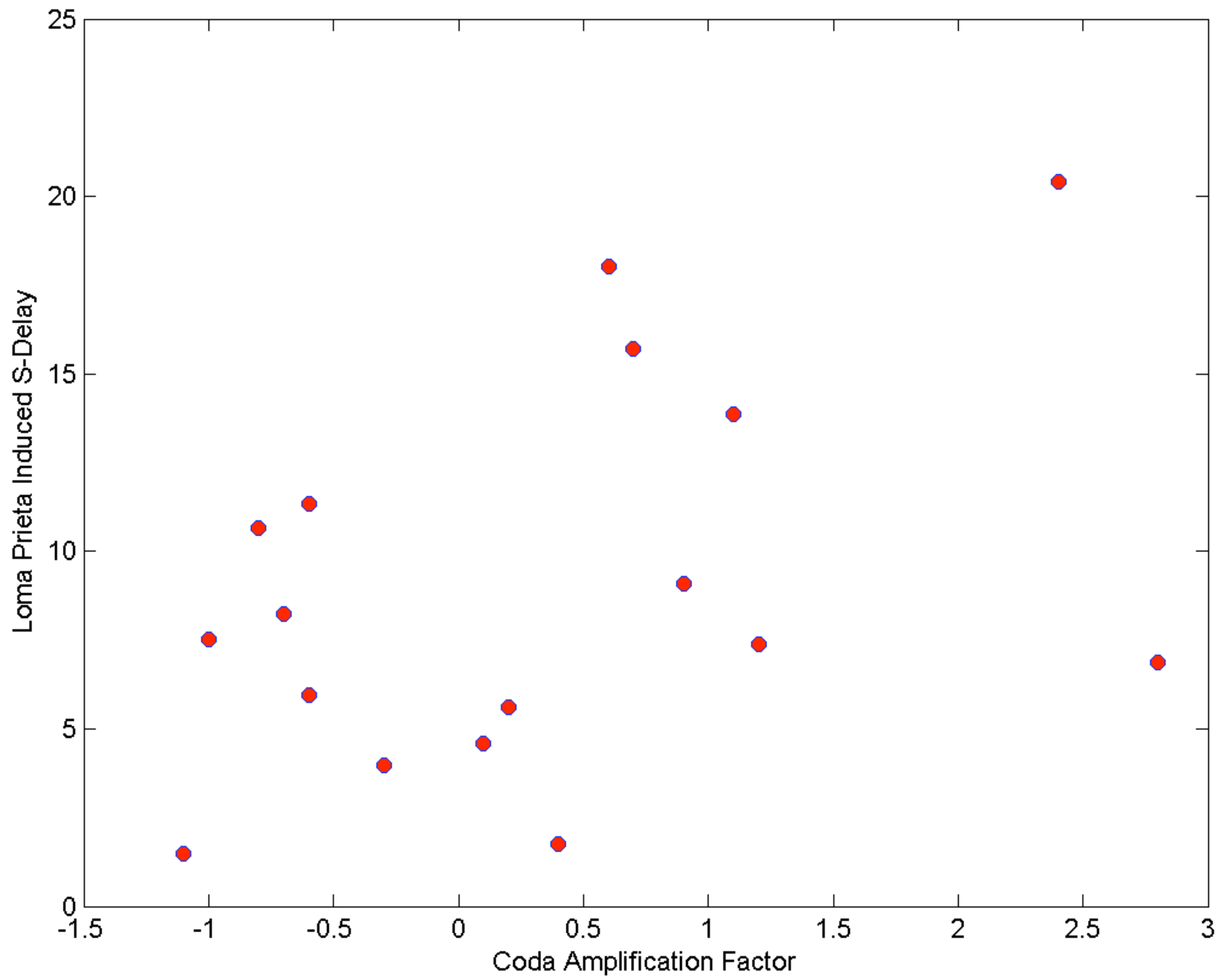
Varies Most Strongly With Surface Geology







Correlation with Coda Amplification

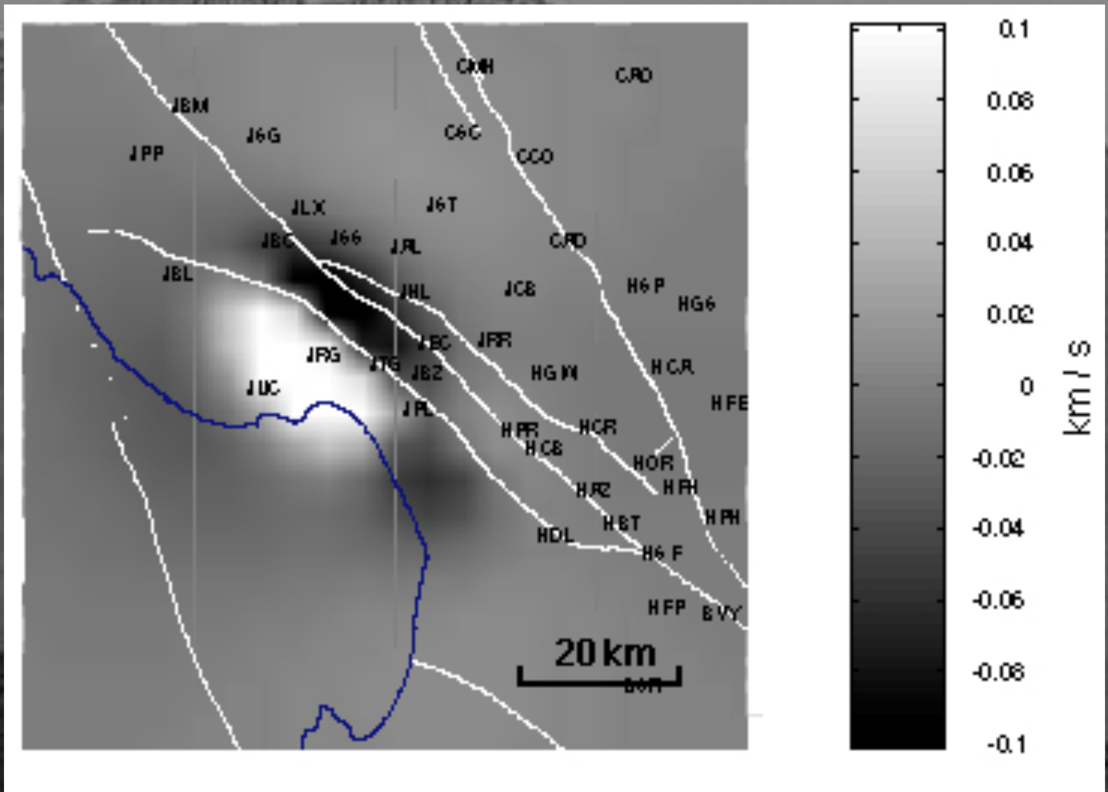


Most Consistent with Site Effects

- Different Sources show similar behavior.
- Nearby stations on different geologic materials show different behavior.
- Velocity perturbations are mostly in the S-coda.
- S-Coda is generated primarily near the receiver.

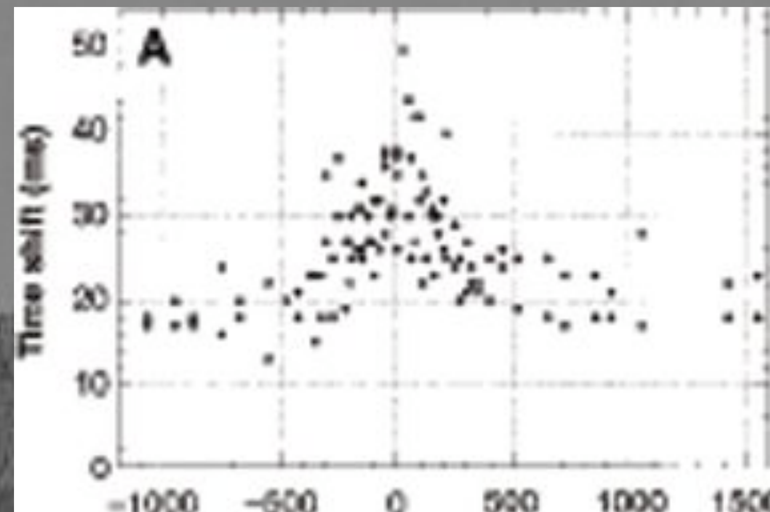
Velocity Change due to Static Stress Change Opening/Closing Cracks?

Inconsistent with our observations since we only observe velocity reductions.



Different from Landers

At Landers, observed velocity reduction confined to the fault zone.



Li, et al. 1998

Our observations, however, indicate widespread velocity reductions.

Velocity Change Due to Lingering Effects of Mainshock Nonlinearity

Damage to rock

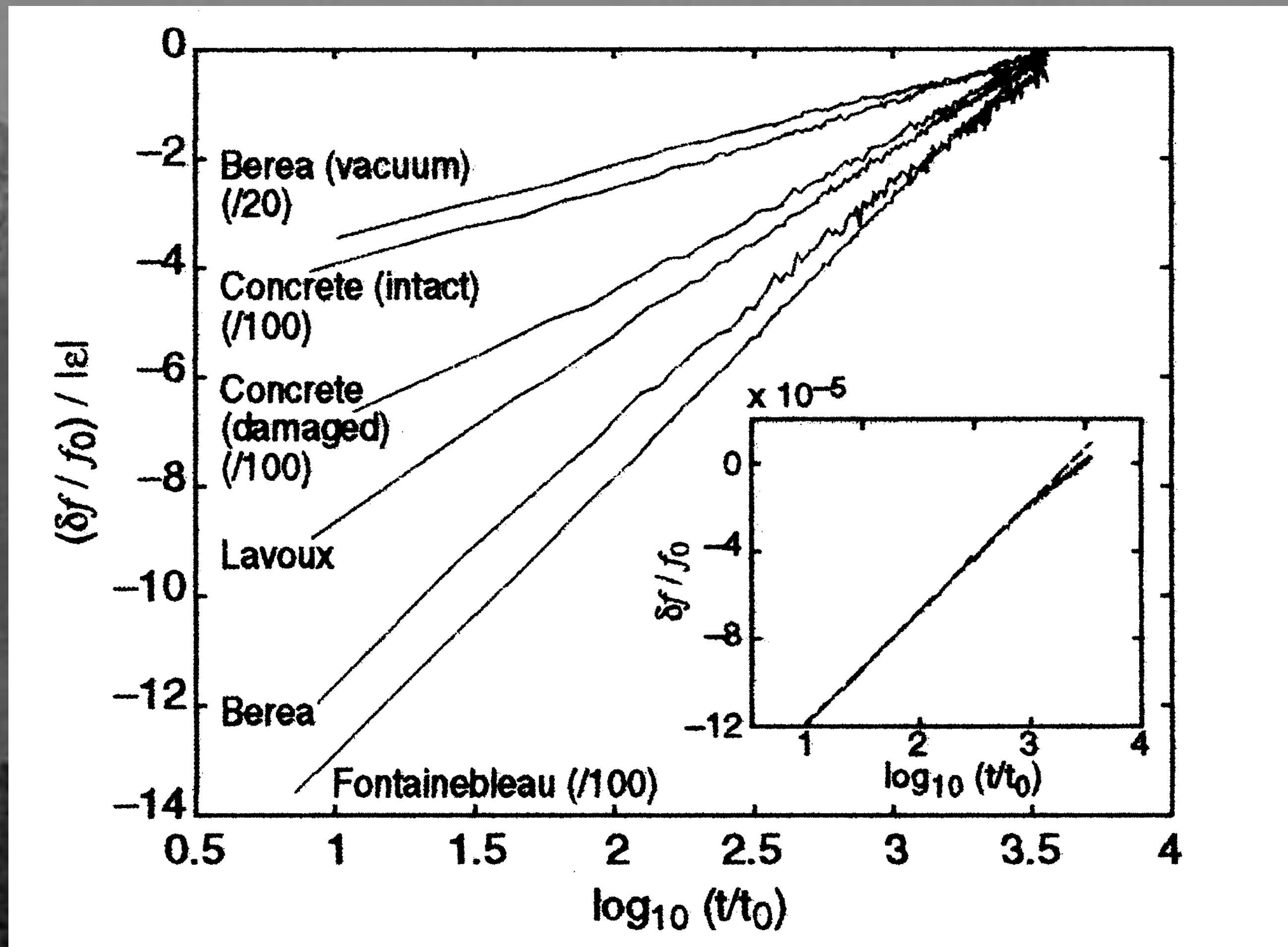
opening/enlargement of existing cracks

formation of new cracks

Nonlinearity

In lab, nonlinearity leads to one-sided velocity change (decrease).

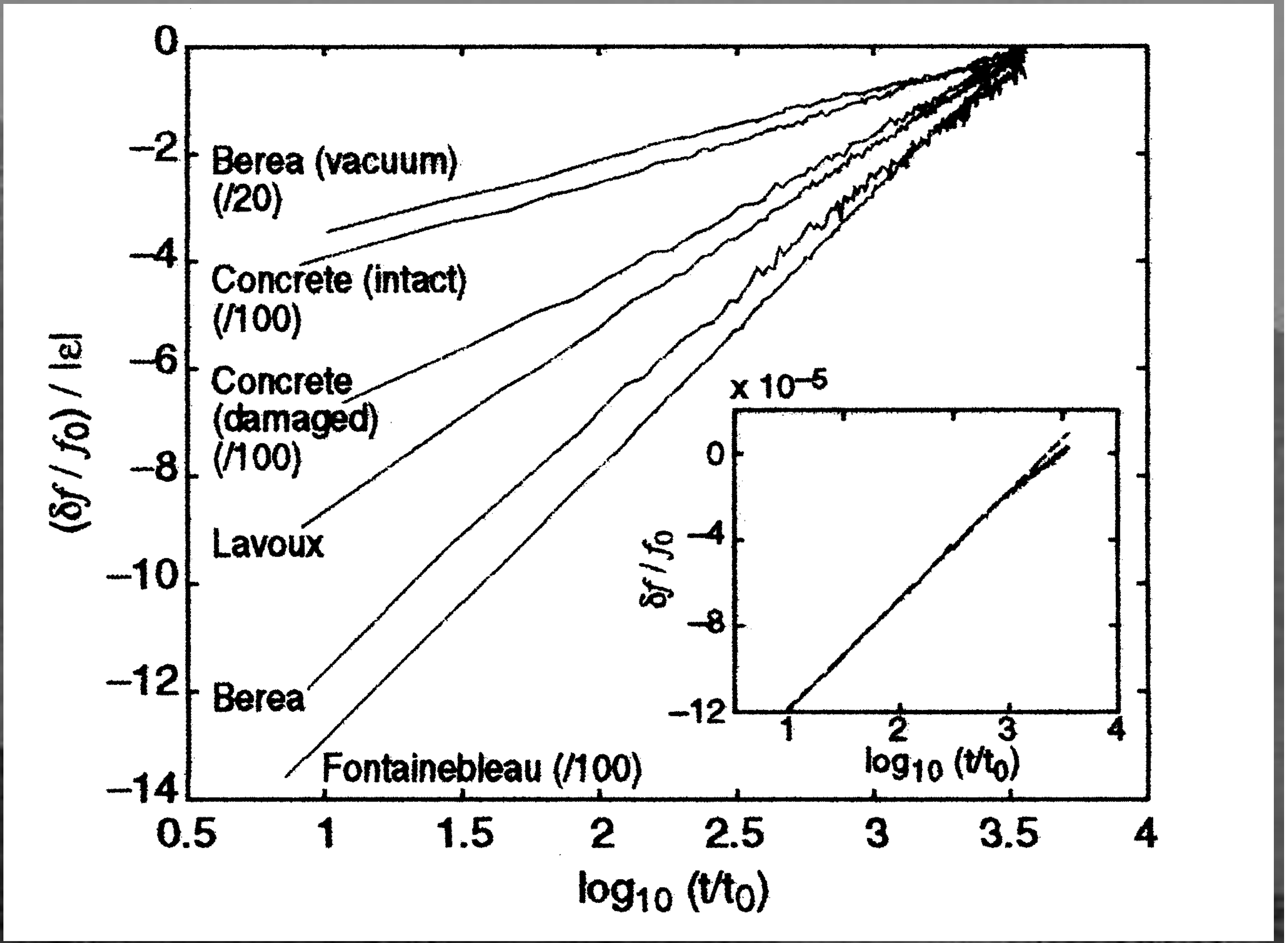
Consistent with our observations.



Nonlinearity

In lab, nonlinearity leads to velocity recovery as log of time.

Consistent with our observations.

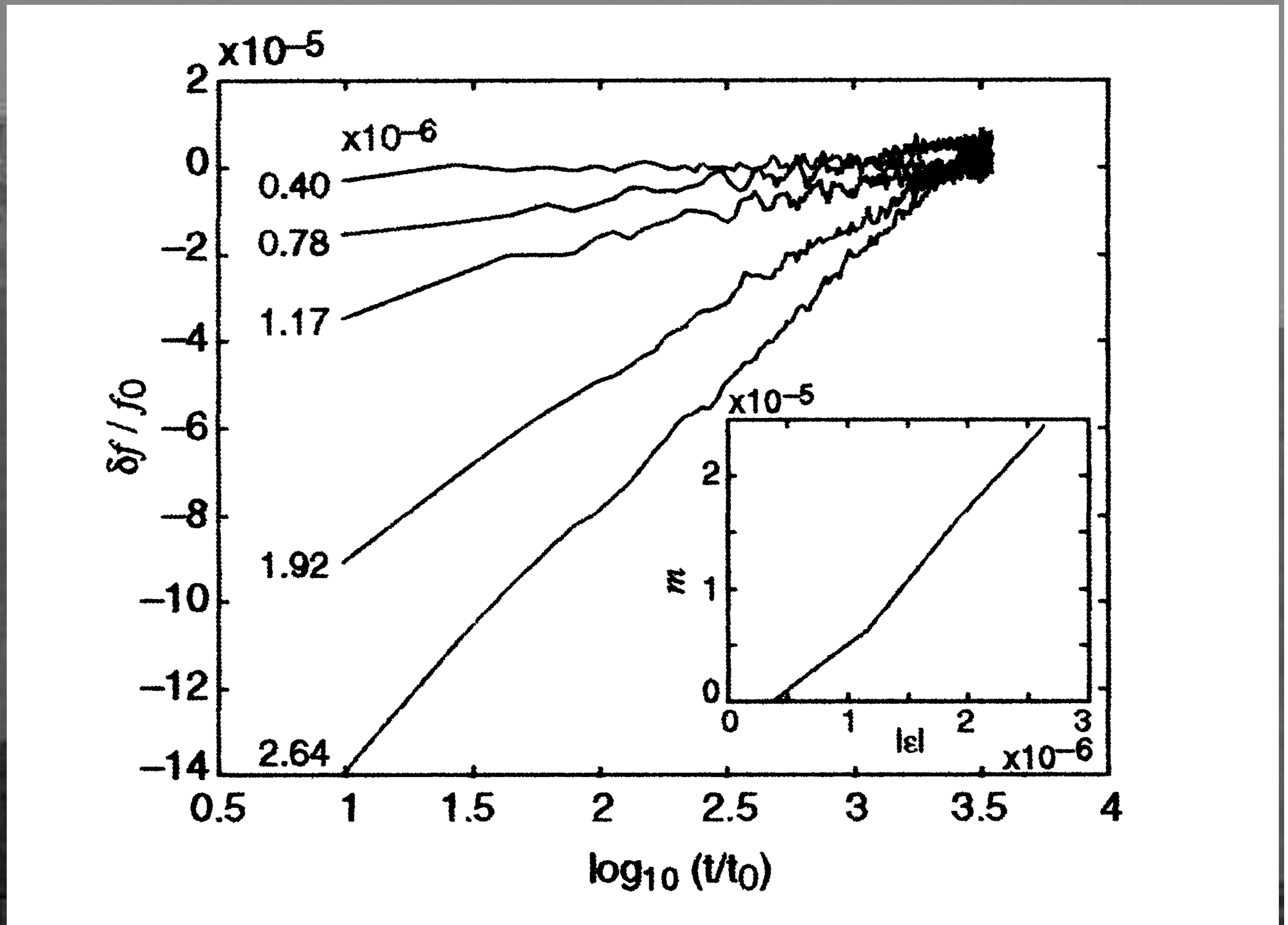


Nonlinearity

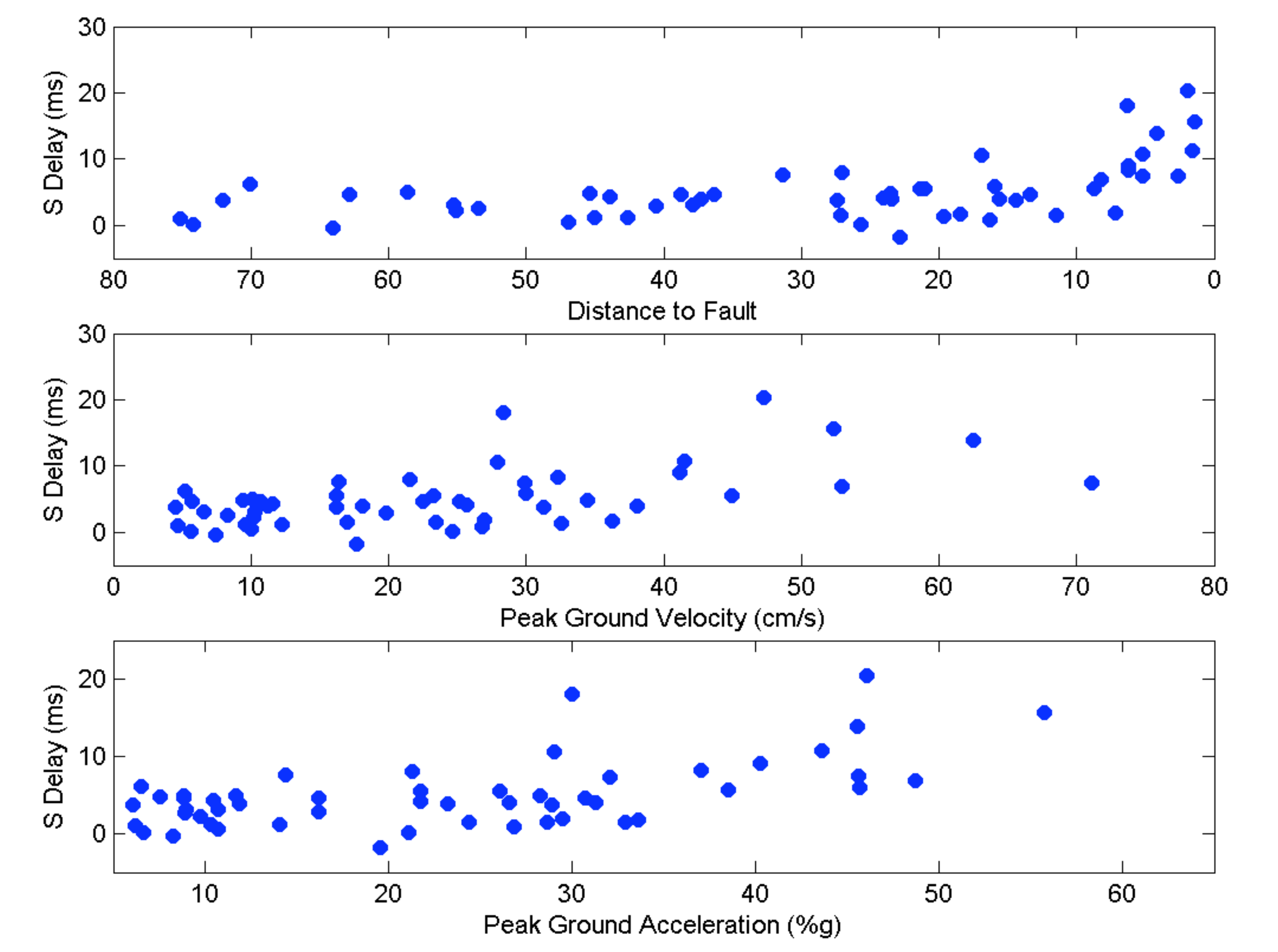
Nonlinearity in the lab at strains of ~10^{-6}

Strains in seismic near-field > 10^{-4}

Lab predicts effect ~ strength of shaking.



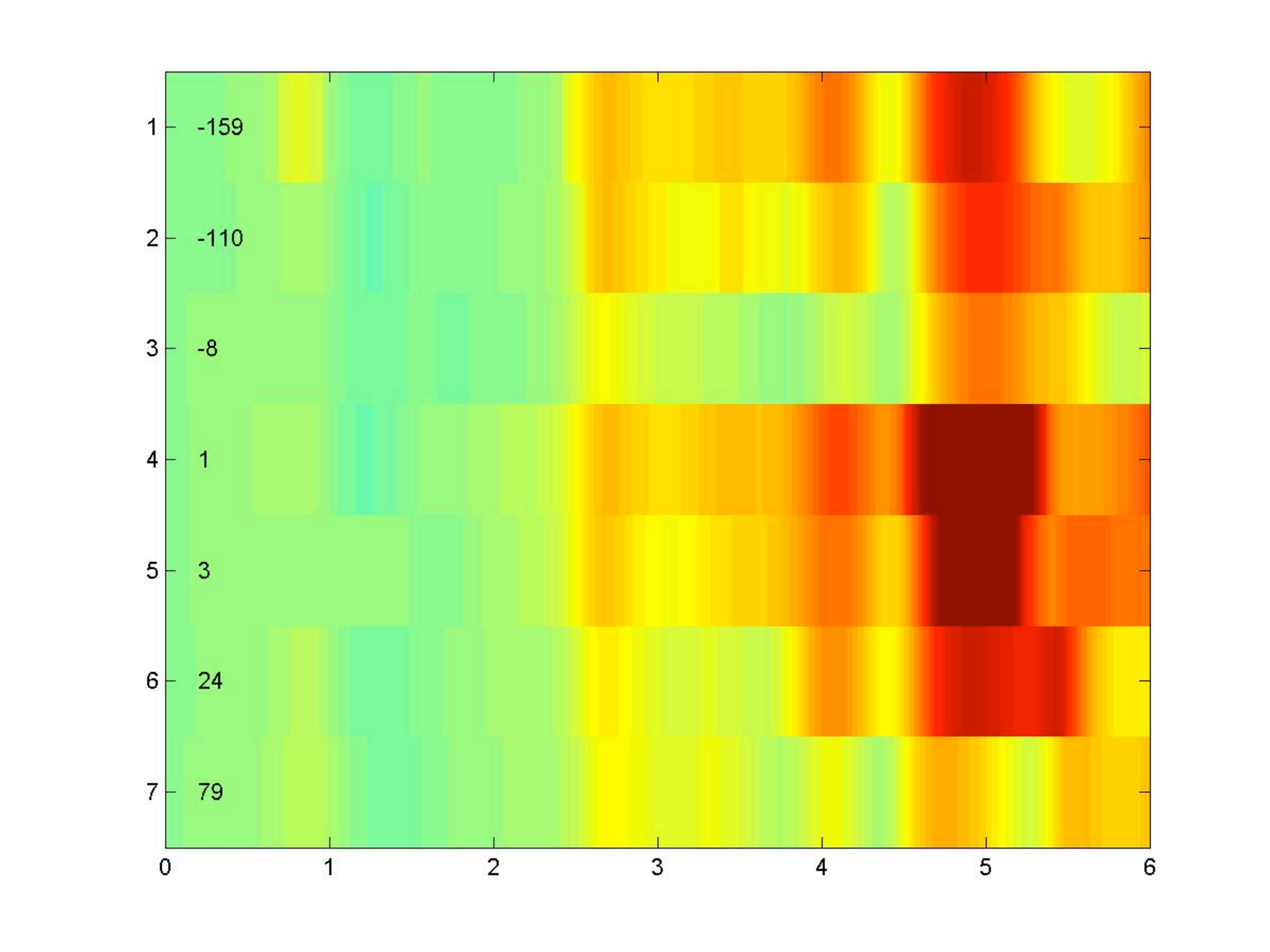
Direct S Delays vs. Strong Ground Motion Parameters



Amplitude of the velocity change ~ strength of shaking.

New way to detect Nonlinearity in Strong ground Motion

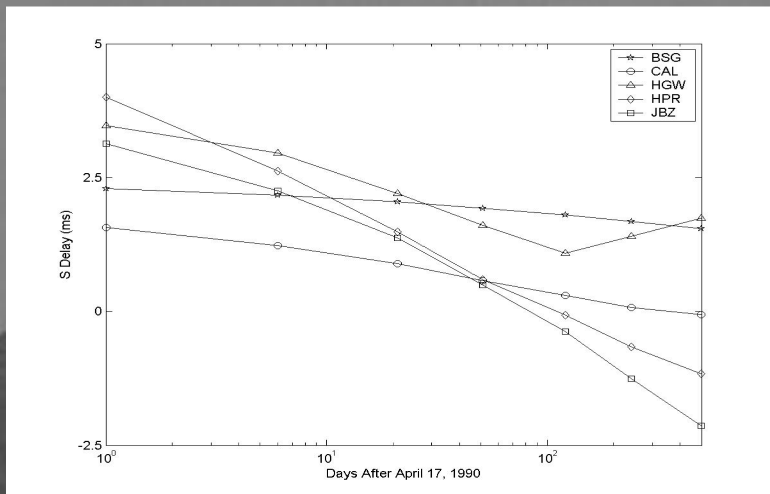
M 5.4 Chittenden Earthquake



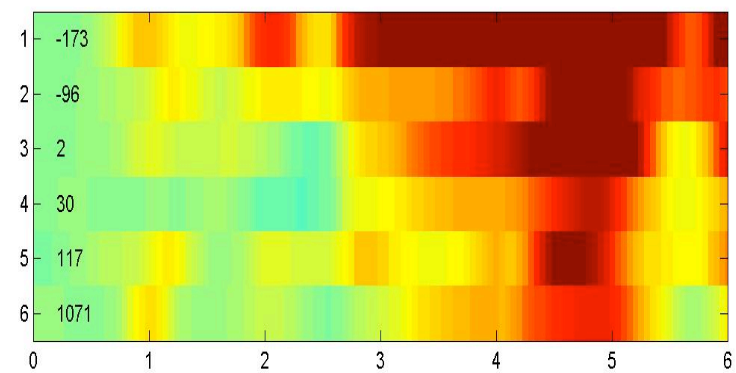
Surprising that such a small earthquake shows this effect.

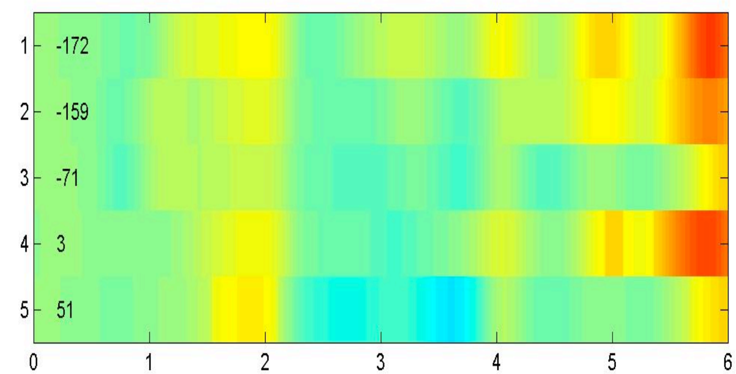
Same Phenomena as Loma Prieta

Healing

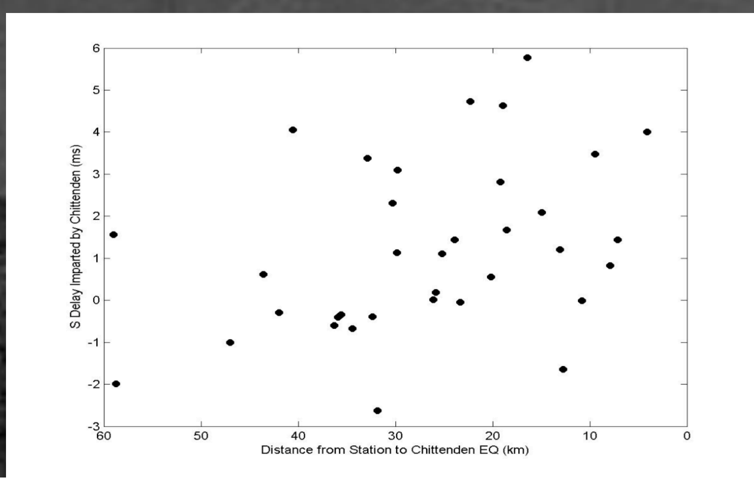


Temporal Recovery





Spatial Distribution



Conclusions

- Velocity change observed after Morgan Hill, Loma Prieta, and Chittenden earthquakes is the lingering effect of mainshock nonlinearity.
- It appears to be widespread.
- Susceptibility depends on rock type.
- Susceptibility may depend on recency of preexisting damage.
- Velocity changes may provide new probe for exploring mechanics of nonlinearity.