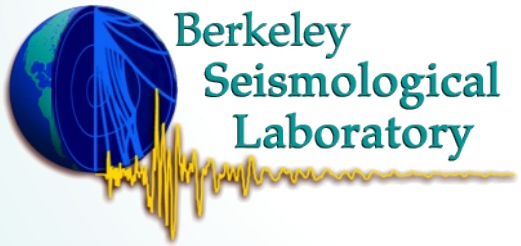
Combining InSAR and GPS data to distinguish coseismic and postseismic slip in the 2003 San Simeon and 2004 Parkfield earthquakes

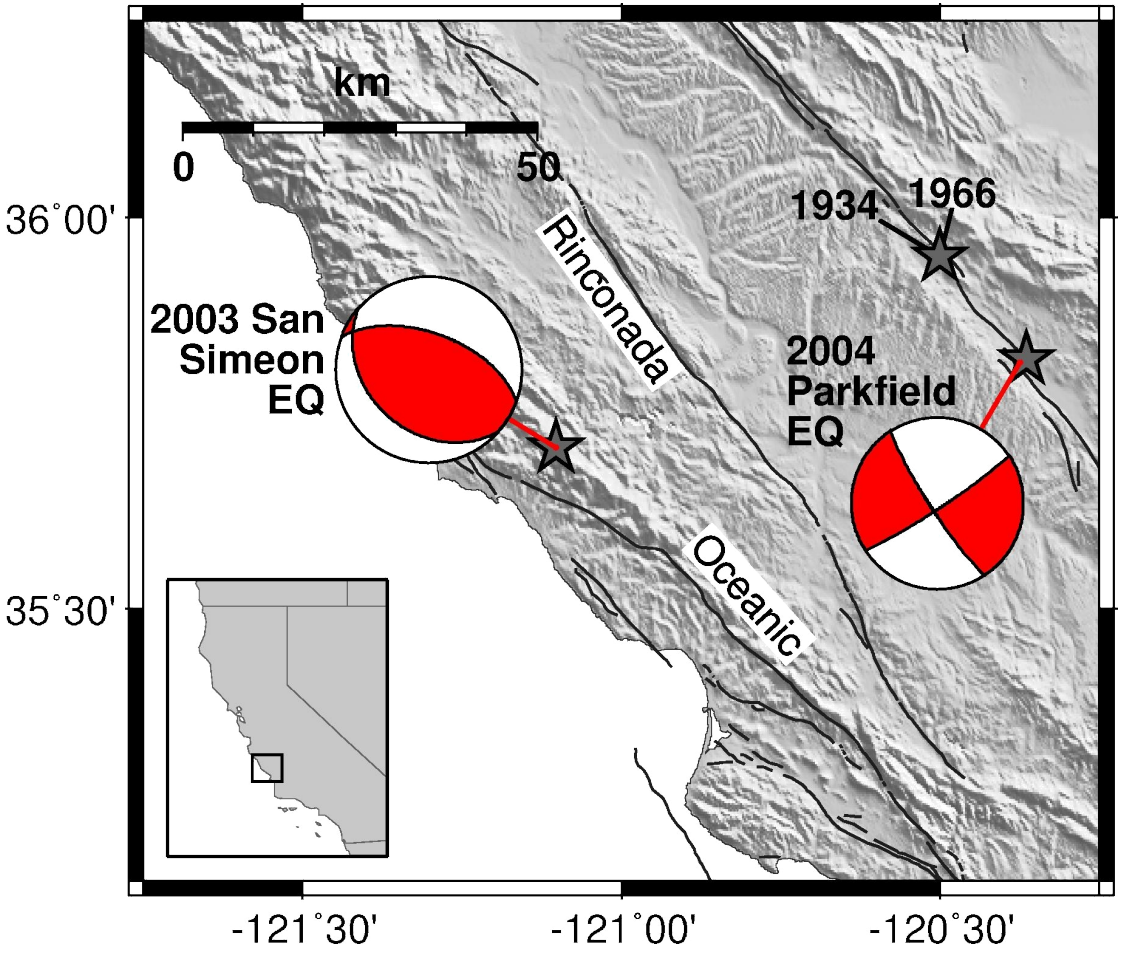


Ingrid A. Johanson

IGCP 565 Workshop

Oct. 11 , 2010

Two Central California Earthquakes



- 10 months and 60 km apart
- 2003 San Simeon
  - ✓M_w6.5
  - ✓Largest EQ in region in last 100 years
  - ✓Little postseismic slip on multiple structures
- 2004 Parkfield EQ
  - ✓M_w6.0
  - ✓Most recent in a series of M6 eqs since 1857.
  - ✓Copious postseismic slip
- Both typify of their

The Parkfield Segment

- Transition Zone

  Some steady creep

  Some strain accumulation

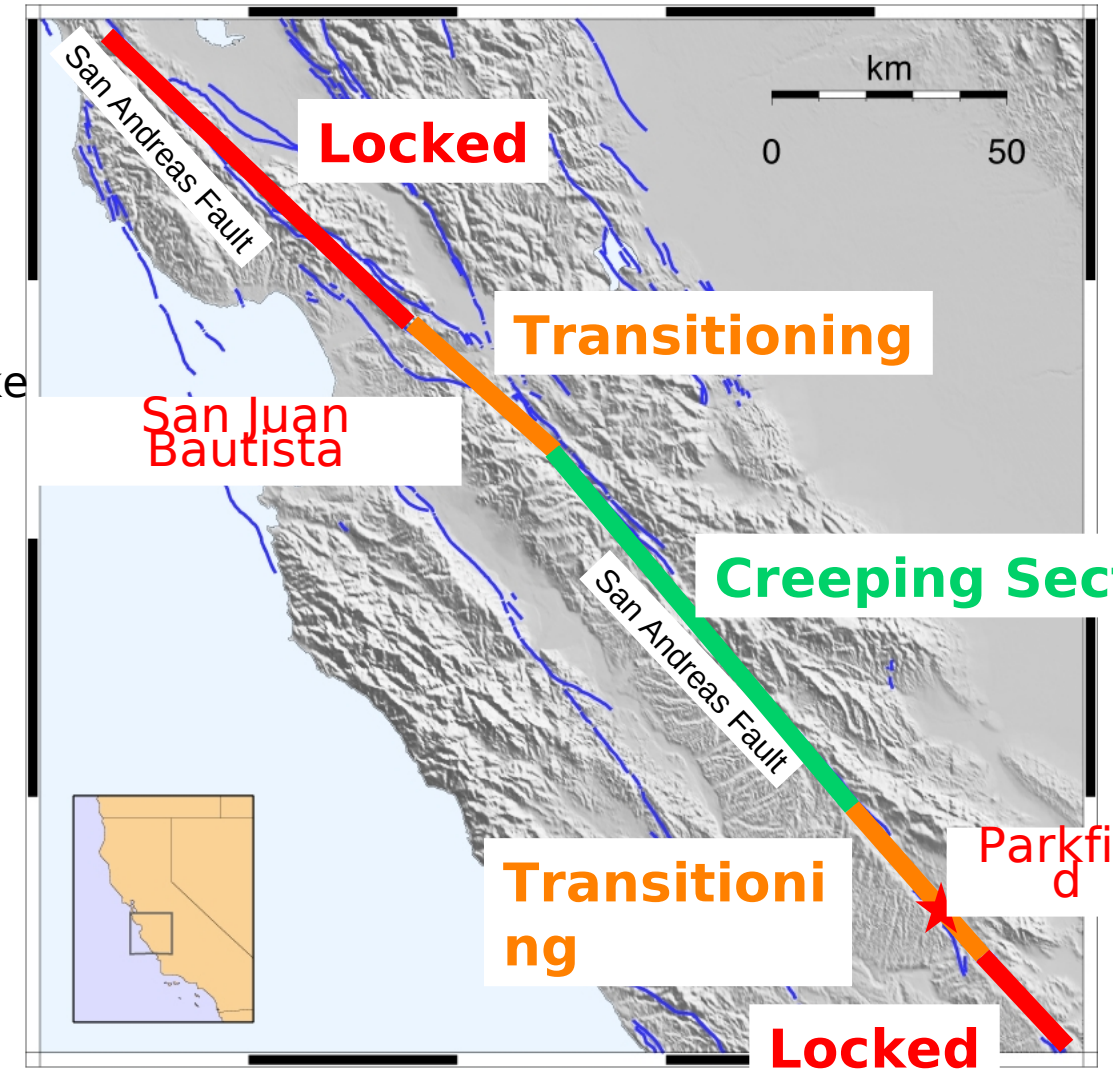
  Transient slip
  - 1993-1996 slow earthquake
  - Copious postseismic slip

- 2004 earthquake

  Nearly as much (or more) aseismic slip as seismic

  Occurred extremely rapidly following the earthquake

  Typical of earthquake on creeping fault (?)



The Parkfield Segment

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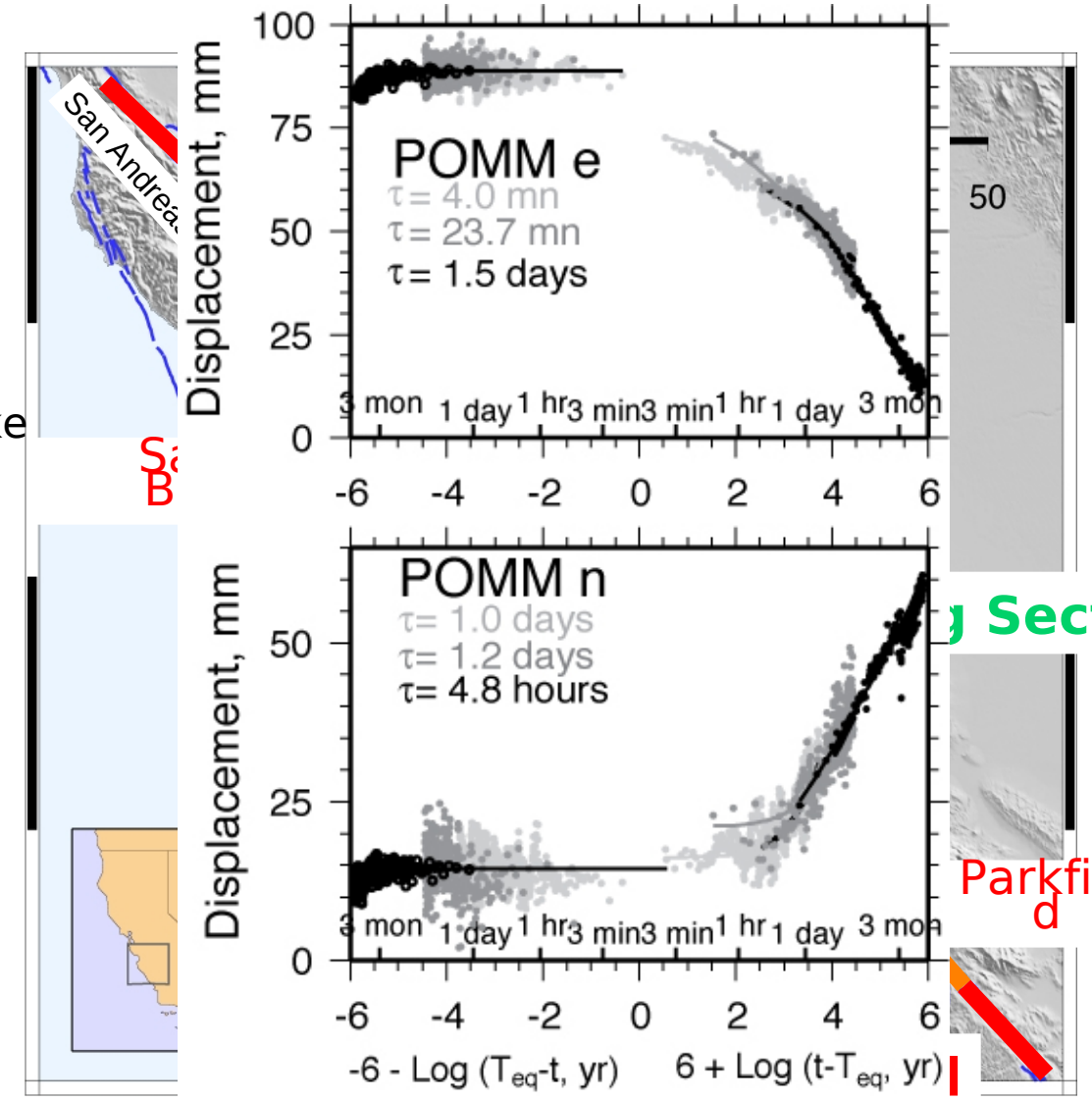
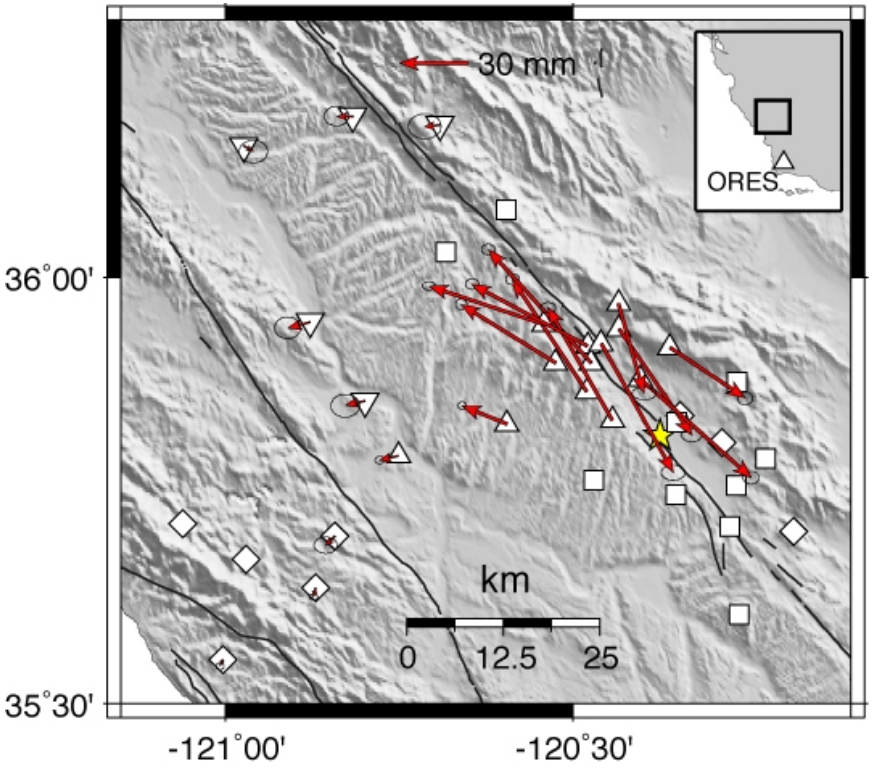


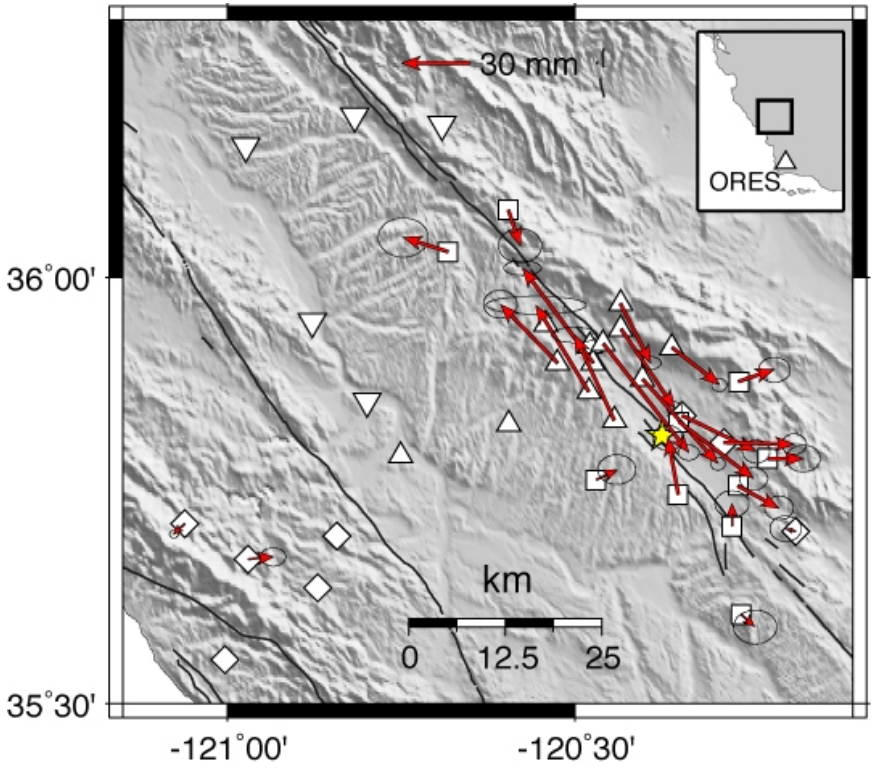
Langbein et al., BSSA 2006

GPS Displacements

Coseismic (d_{pk})



Postseismic (A_{ps})



Displacements relative to station ORES

The Parkfield Segment

- Transition Zone

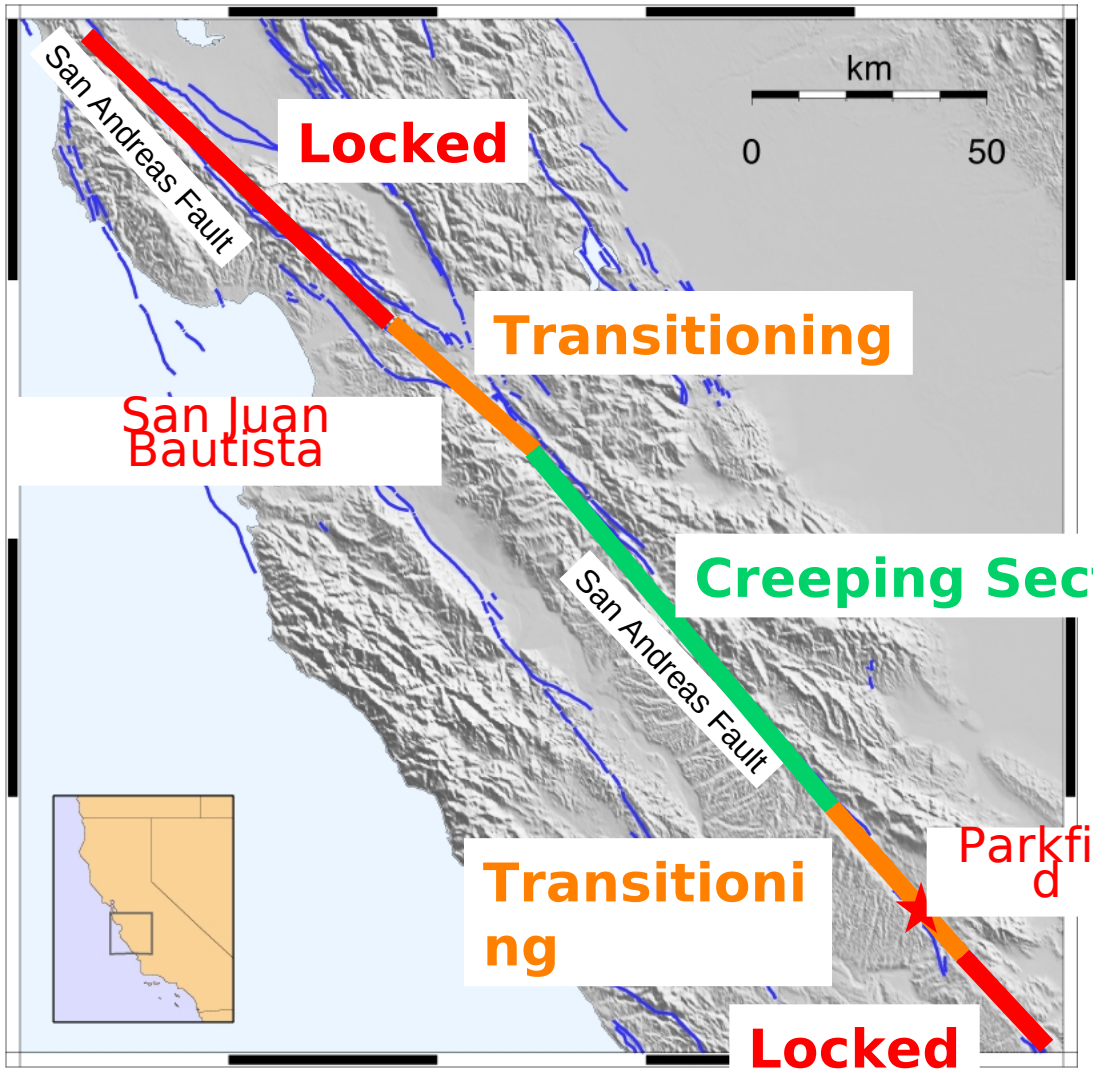
  Heterogeneous distribution of fault frictional regimes

- 2004 earthquake

  Good separation of seismic vs. aseismic slip:

  -How transition is accommodated

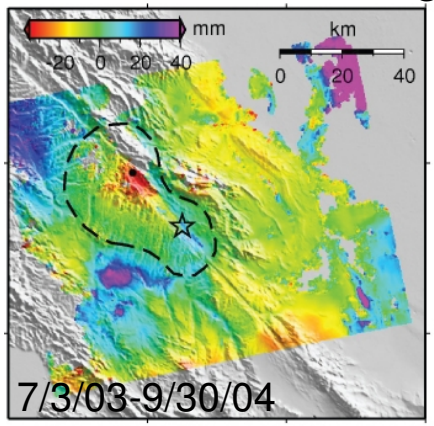
  -What can we expect on other faults

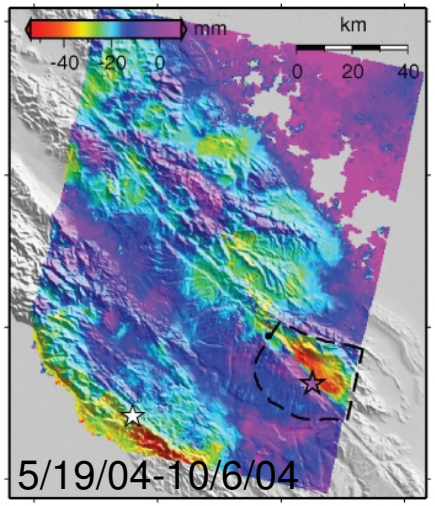


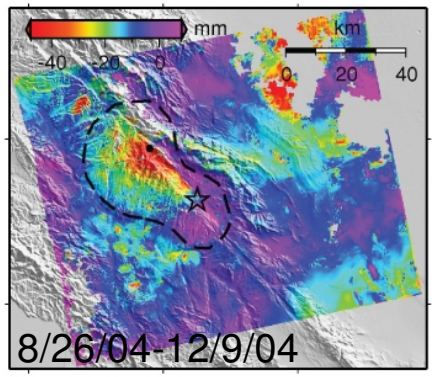
Parkfield Interferograms

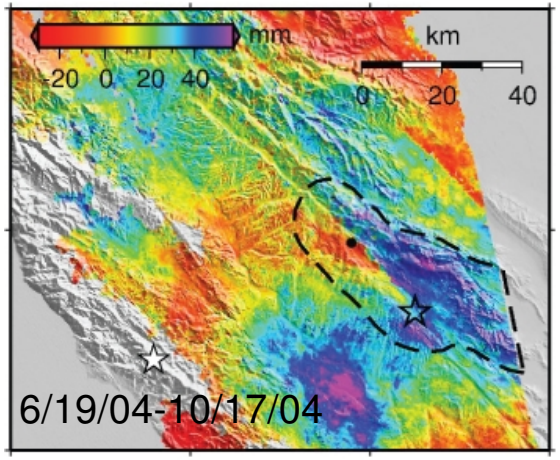
ENVISAT Interferograms

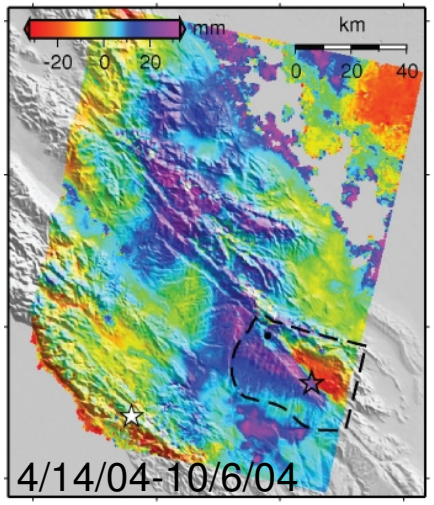
RADARSAT Interfs.

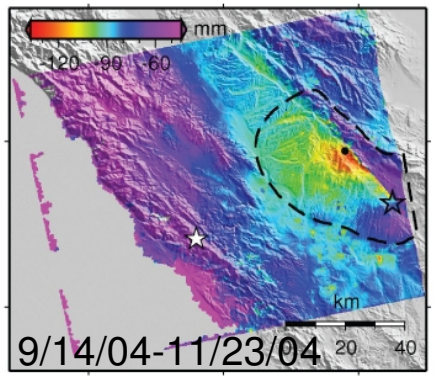


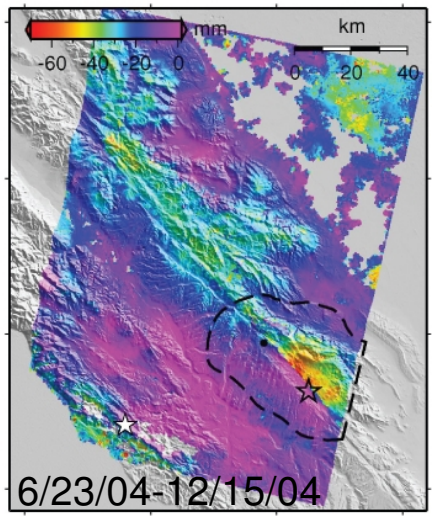


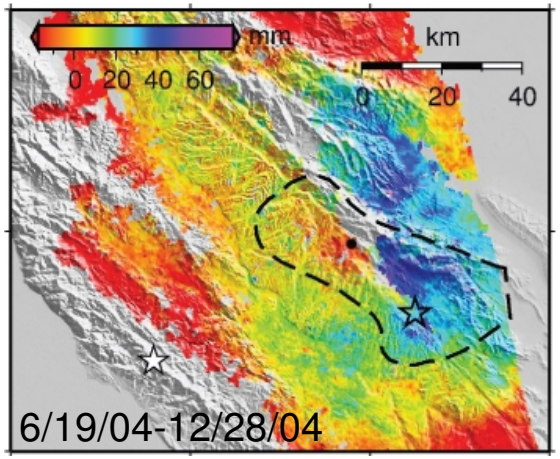












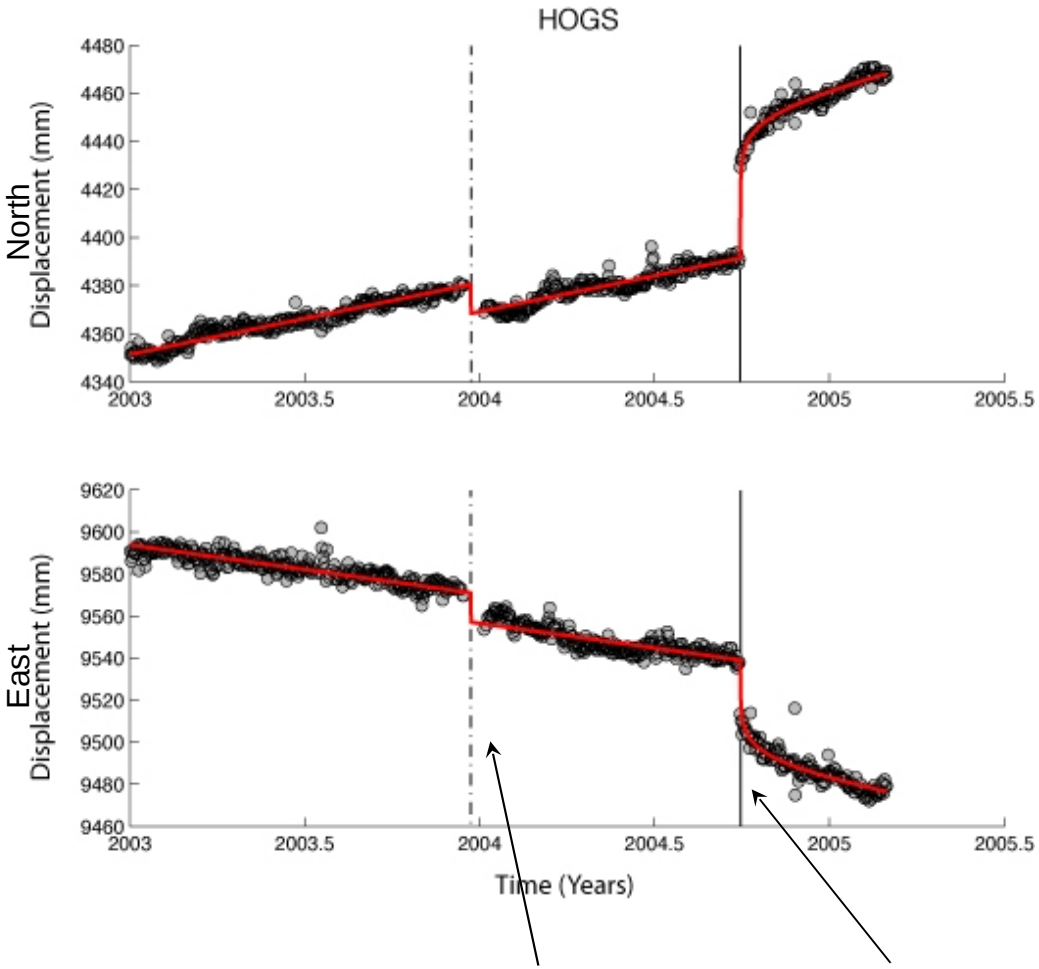
Small earthquake → low signal to noise

● SAFOD

☆ Parkfield EQ epicenter

☆ San Simeon EQ epicenter

Time History from GPS



Fit time-series with…

Steady Interseismic rate

Offset at San Simeon EQ (12/22/2003)

Offset at Parkfield EQ (d_{pk})

Exponential after Parkfield EQ

$$A_{ps}\left(1 - e^{-(t - t_{pk})/\tau}\right)$$

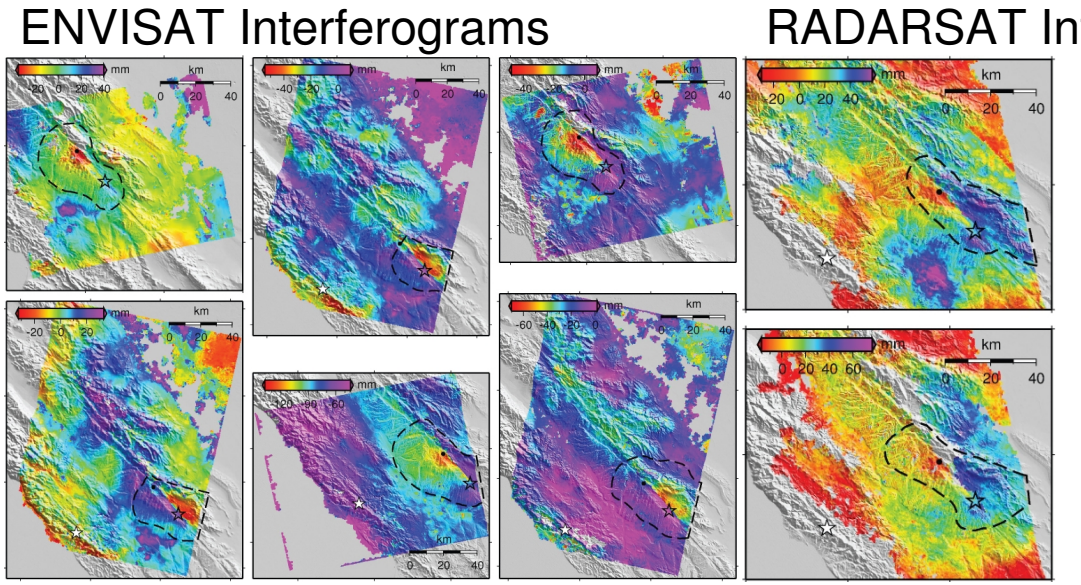
A_{ps} = Amplitude

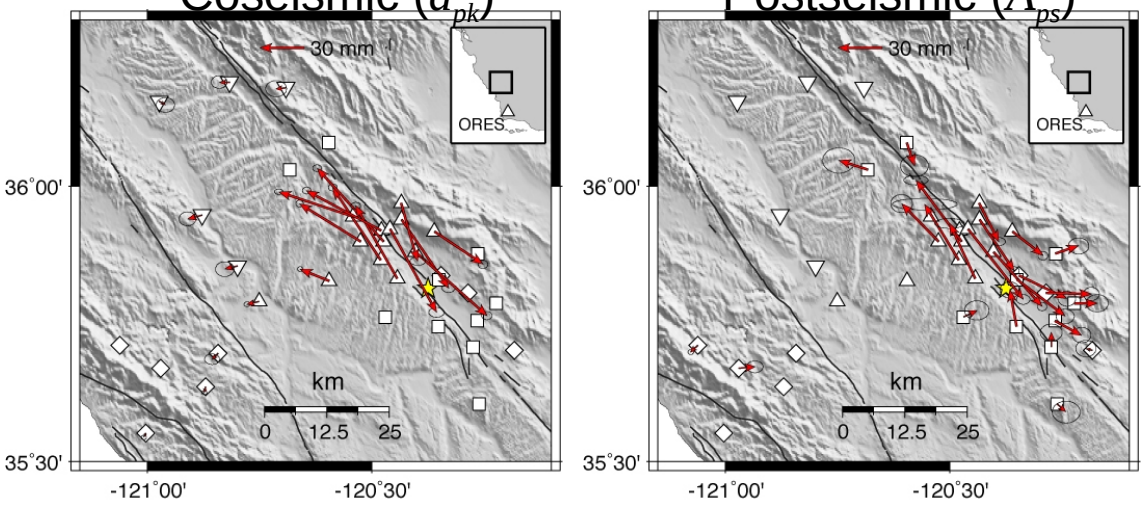
τ = decay time constant

t = time

t_{pk} = date of Parkfield earthquake

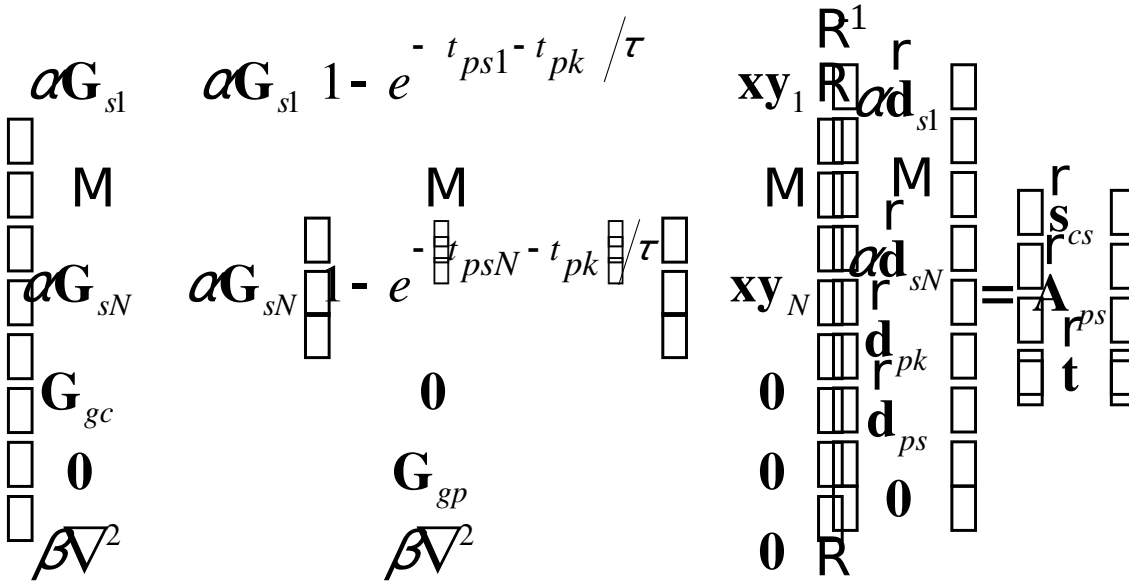
Geodetic Data for Parkfield EQ





- 8 Interferograms
  - co-, post-intermixed
- 2 sets GPS displacements
  - co-, post-separate
- 1 model
  - BOTH co-, post-slip

Inversion Formulation



$\dot{\mathbf{d}}_{sN}$ =InSAR data

$\mathbf{d}_{pk}, \mathbf{d}_{ps}$ =coseismic and postseismic GPS data

α =InSAR data weight

$\mathbf{G}_{sN}, \mathbf{G}_{gc}, \mathbf{G}_{gp}$ =Green's functions for InSAR, co- and postseismic GPS

τ =decay time constant

t_{psN} =Enddate of Interferogram

t_{pk} =date of Parkfield earthquake

β =weight of Laplacian smoothing operator (∇^2)

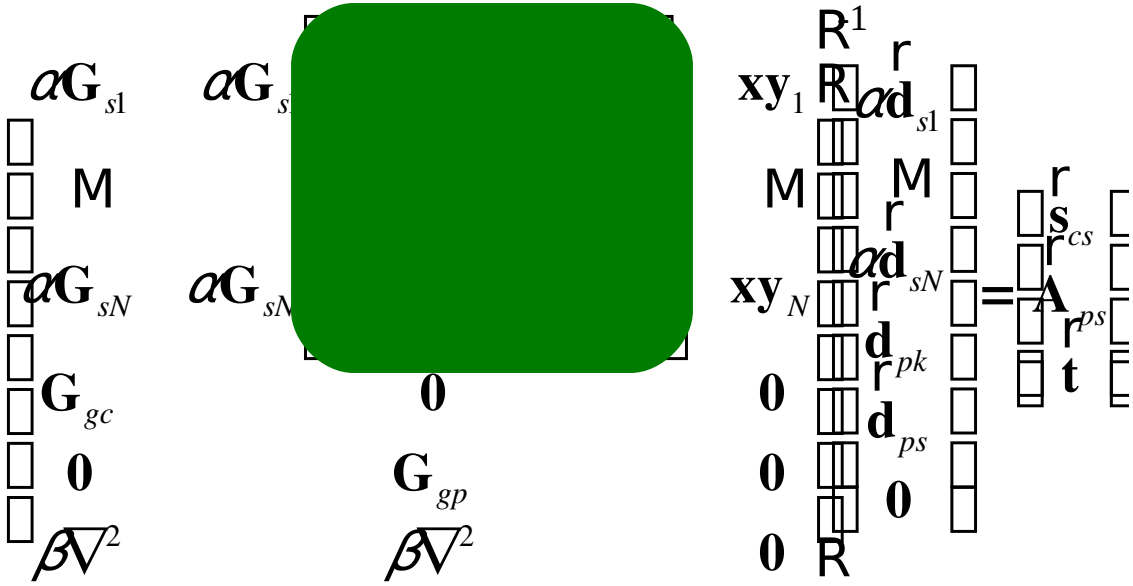
$\mathbf{s}_{cs}$ =coseismic slip

$\mathbf{A}_{ps}$ =amplitude of postseismic exponential

$\mathbf{t}$ =tilt across each interferogram

$\mathbf{xy}_N$ = Green's functions for tilt

Inversion Formulation



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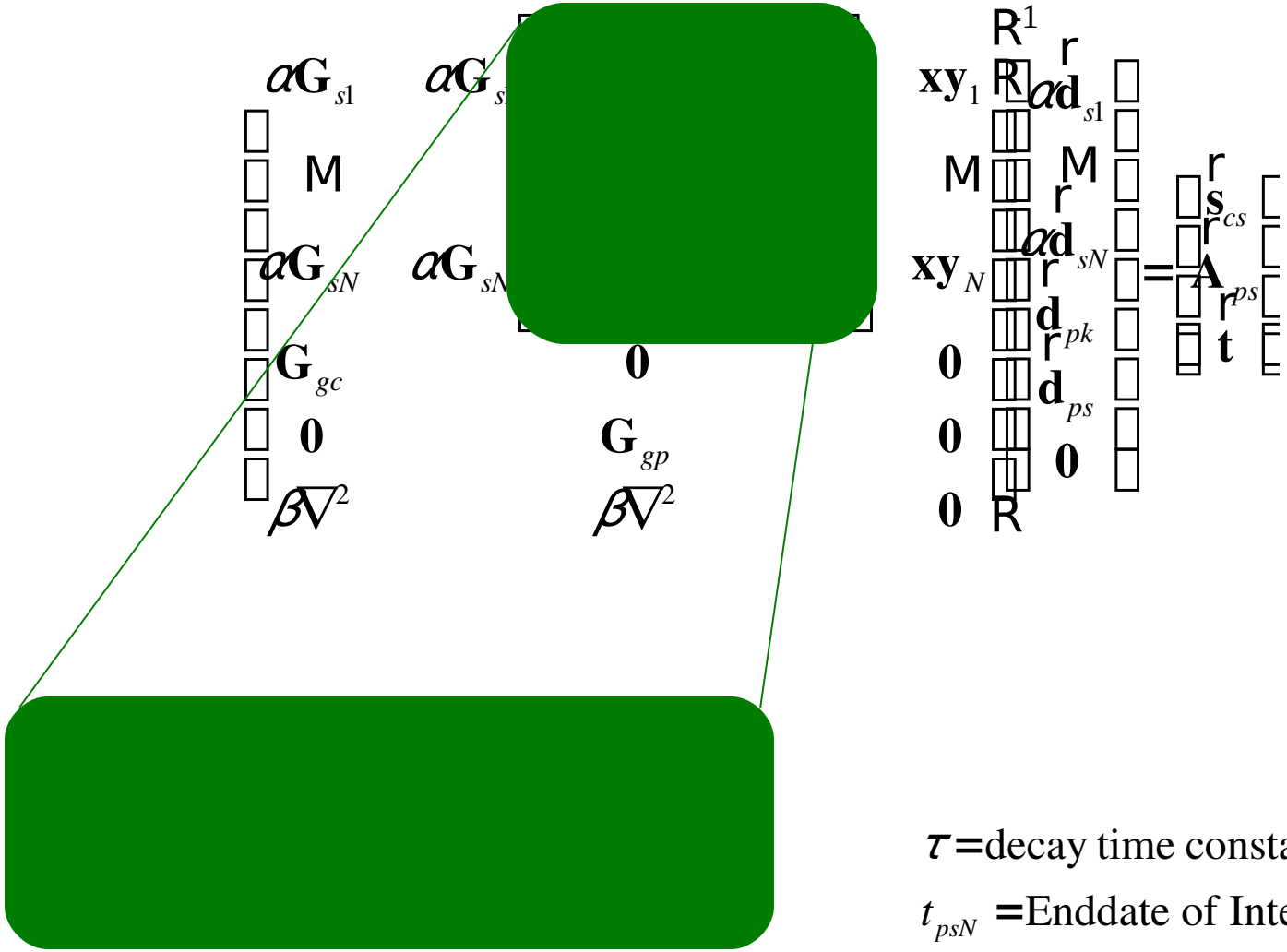


τ = decay time constant

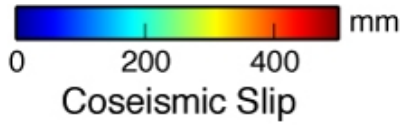
t_{psN} = Enddate of Interferogram

t_{pk} = date of Parkfield earthquake

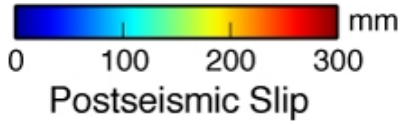
Slip during the Parkfield Earthquake

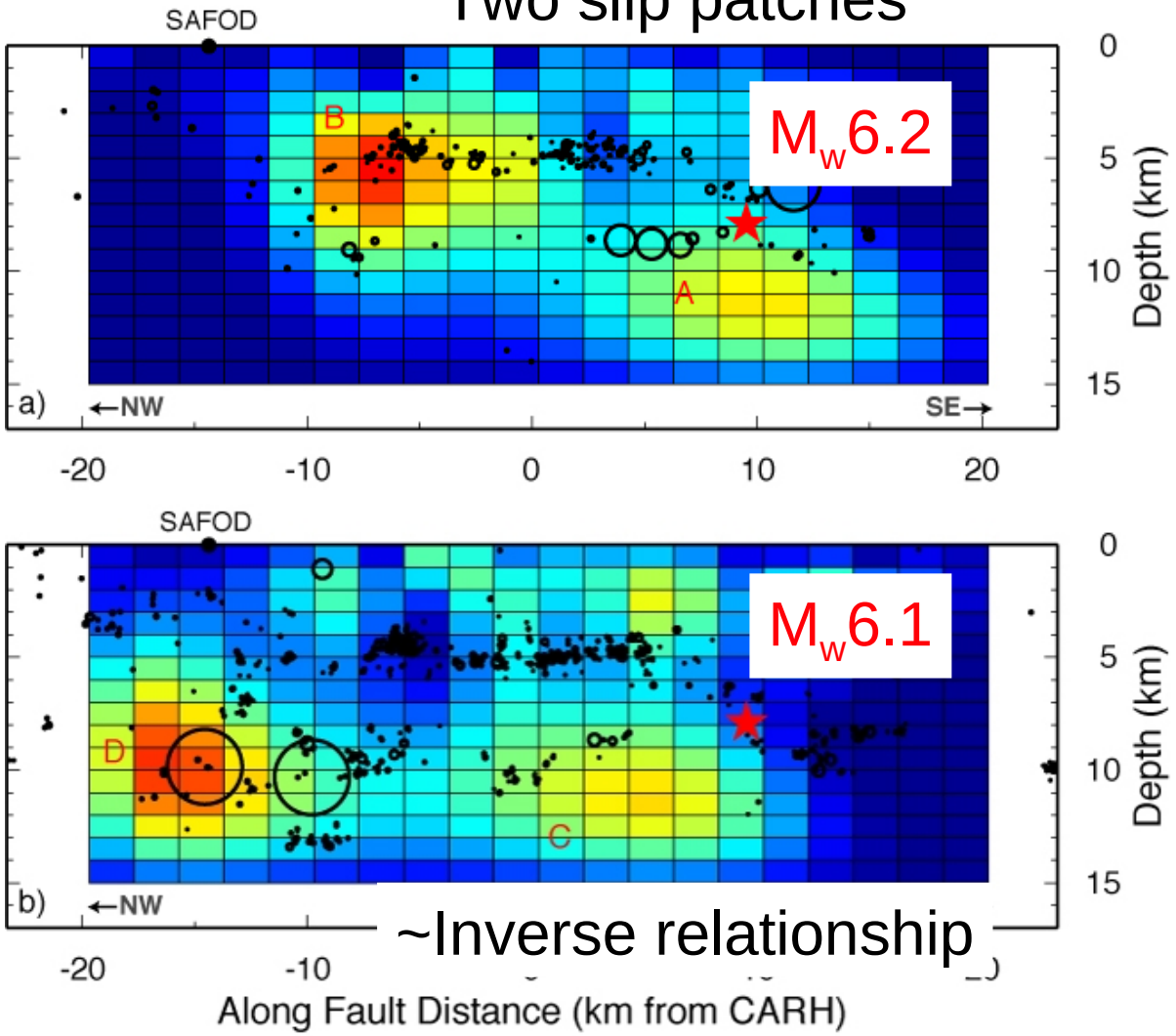
Two slip patches

Coseismic Slip (seismic)



Postseismic Slip (aseismic)





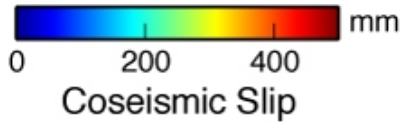
~Inverse relationship

★ 2004 hypocenter

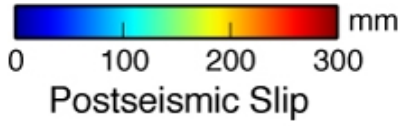
○ Double-Difference relocated seismicity (Thurber et al., 2006)

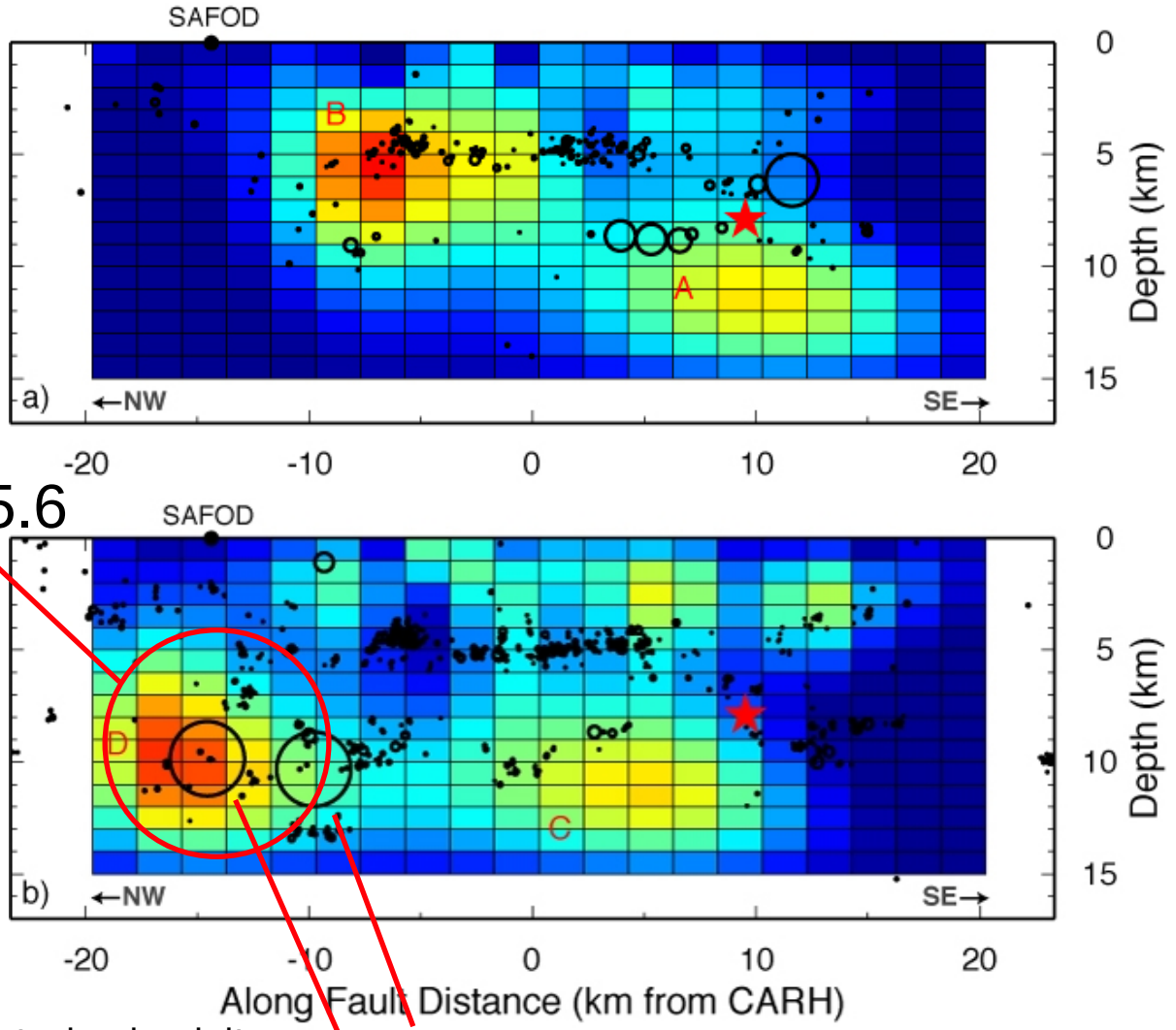
Postseismic slip and Aftershocks

Coseismic Slip (seismic)



Postseismic Slip (aseismic)





★ 2004 hypocenter

○ Double-Difference relocated seismicity (Thurber et al., 2006)

San Simeon Earthquake

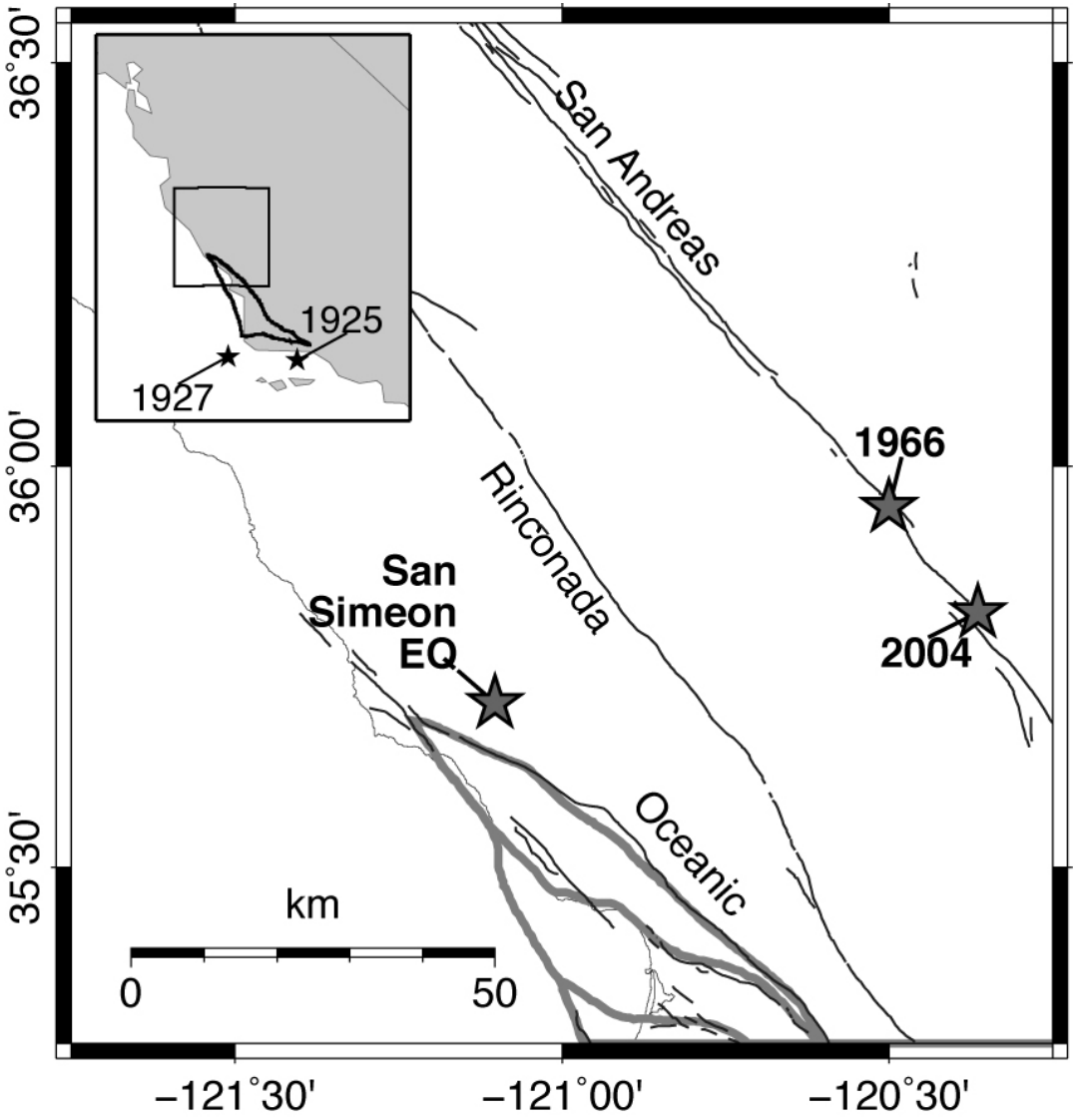
December 22, 2003; Mw6.5

Occurred on northern edge of Los Osos Domain

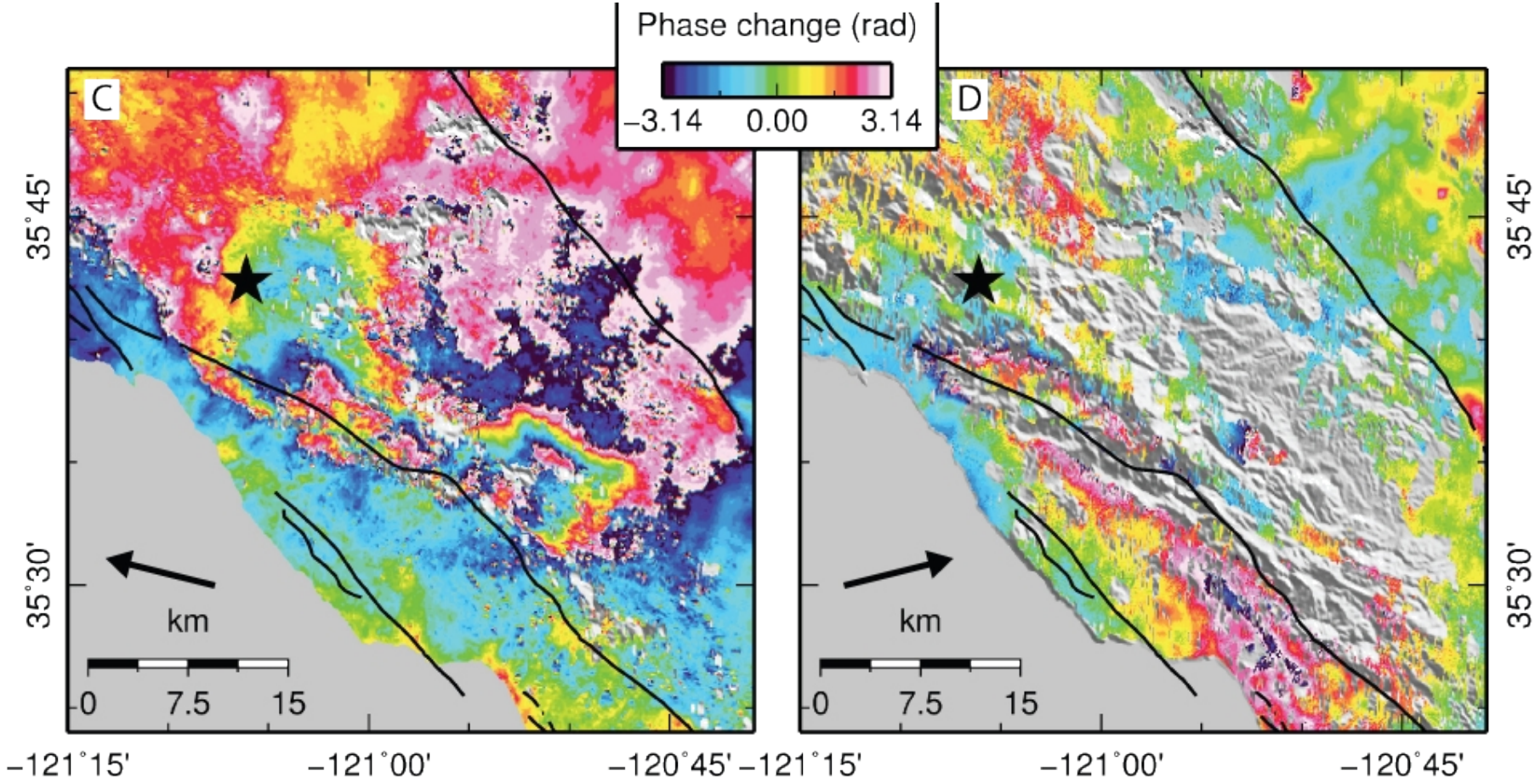
Oceanic fault: low slip rate and non-creeping

Postseismic slip ~14% of coseismic with complex spatial pattern.

Example of Coast range building event



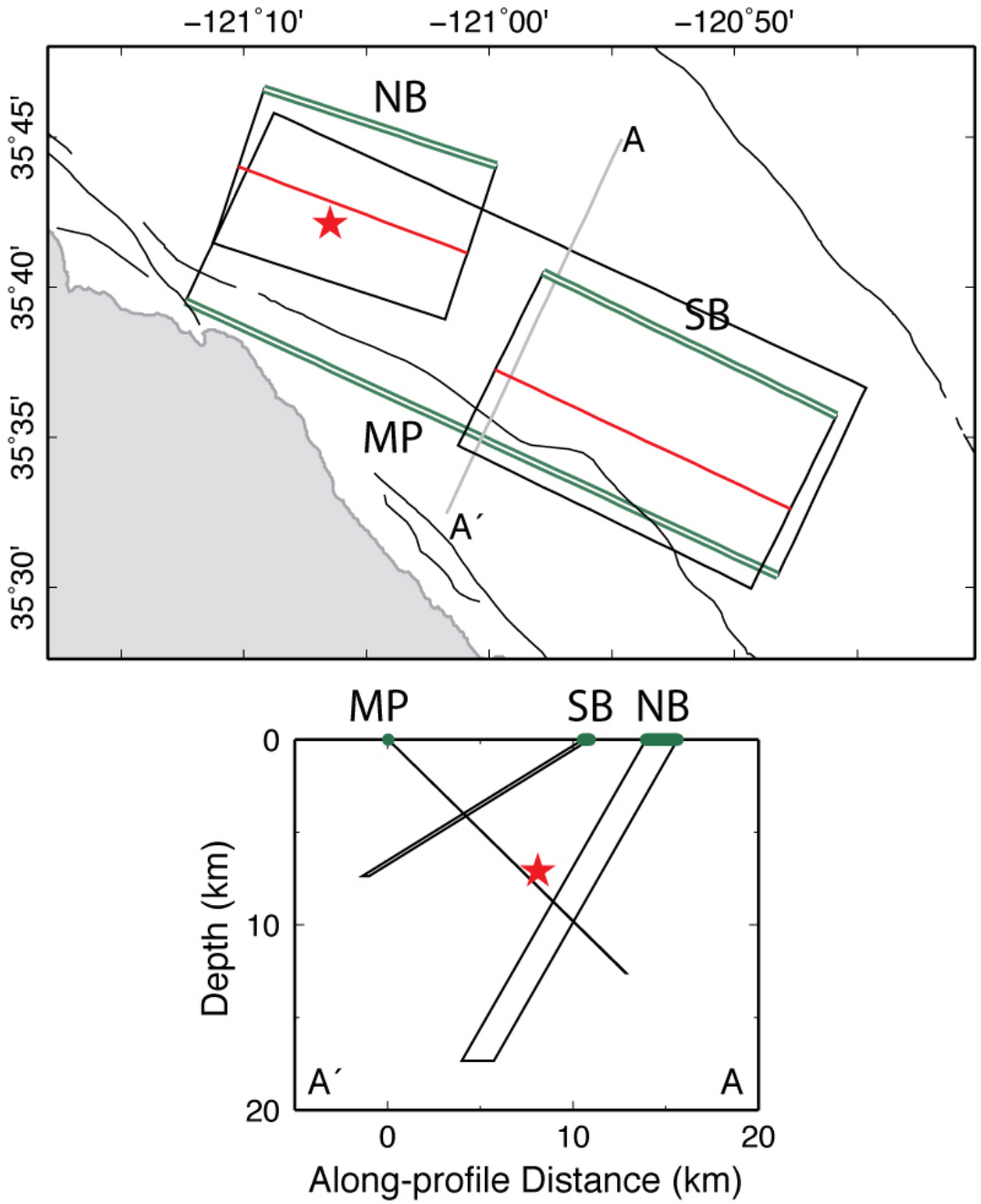
2 Postseismic Interferograms



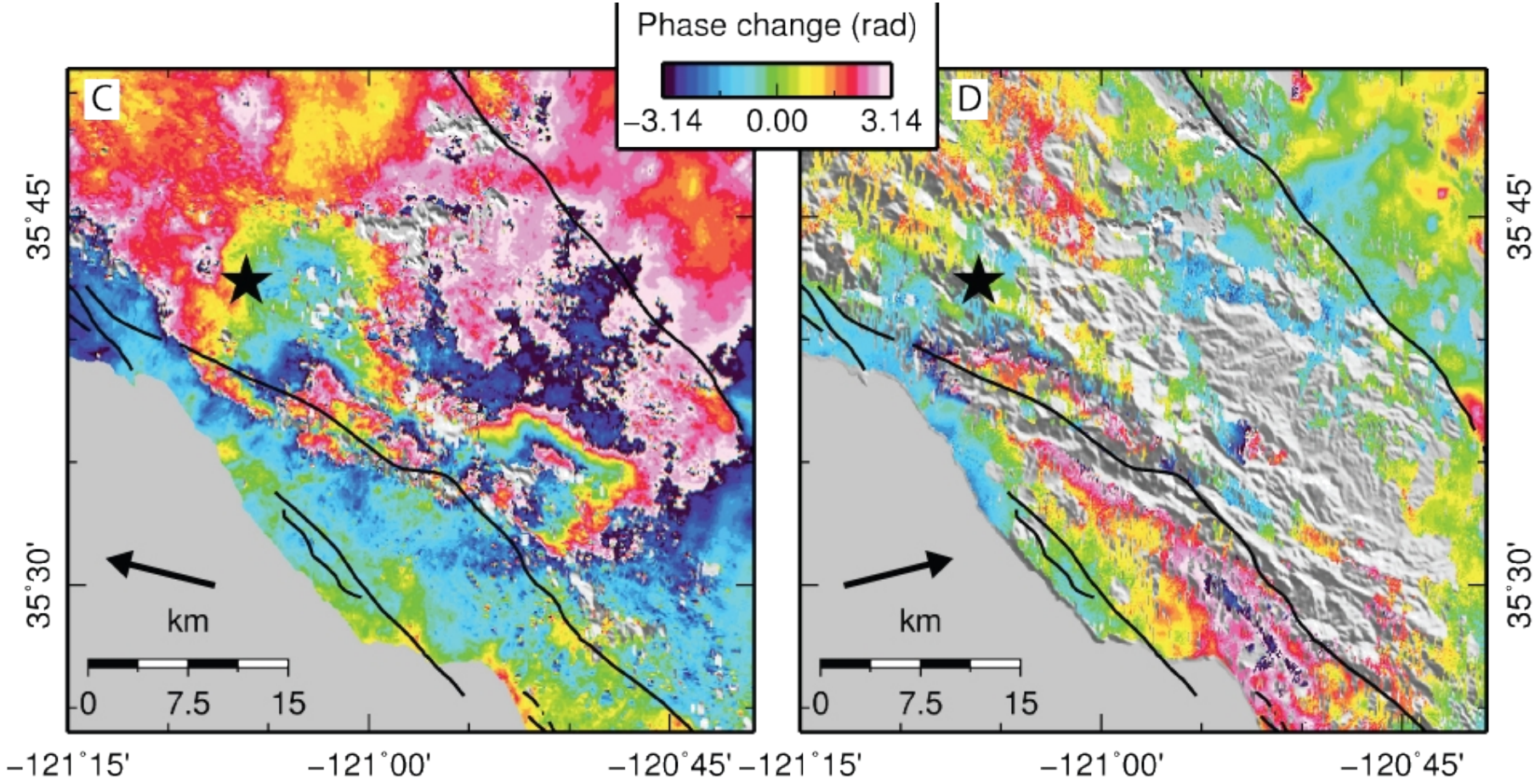
12/31/2003 - 2/4/2004
Descending ERS

1/20/2004 - 4/1/2004
Ascending Radarsat

1 cycle = 2.8 cm


−121°10'
−121°00'
−120°50'
35°45'
35°40'
35°35'
35°30'
NB
A
SB
MP
A´
MP
SB
NB
0
10
20
Depth (km)
A´
A
0
10
20
Along-profile Distance (km)

2 Postseismic Interferograms



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Descending ERS

1/20/2004 - 4/1/2004
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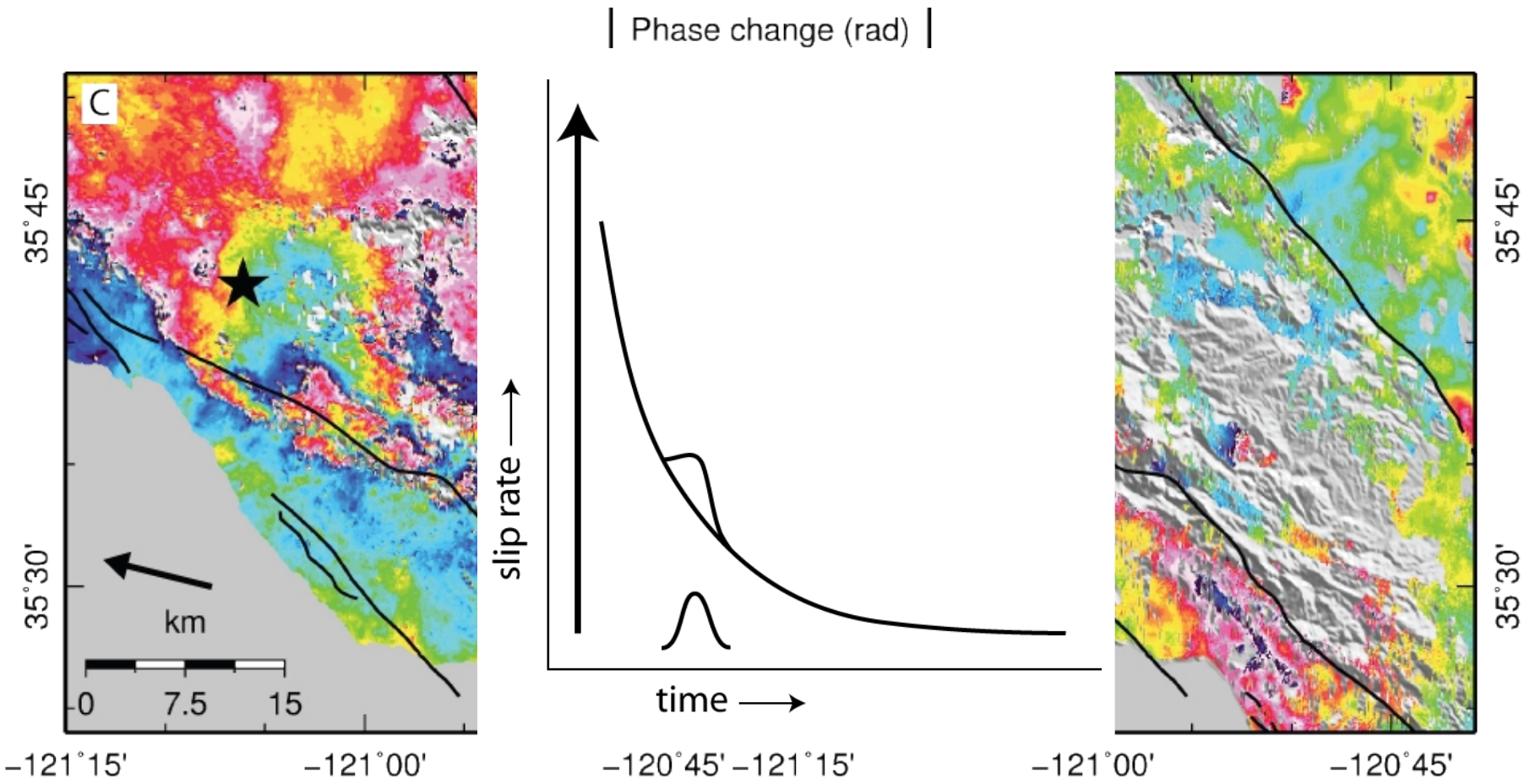


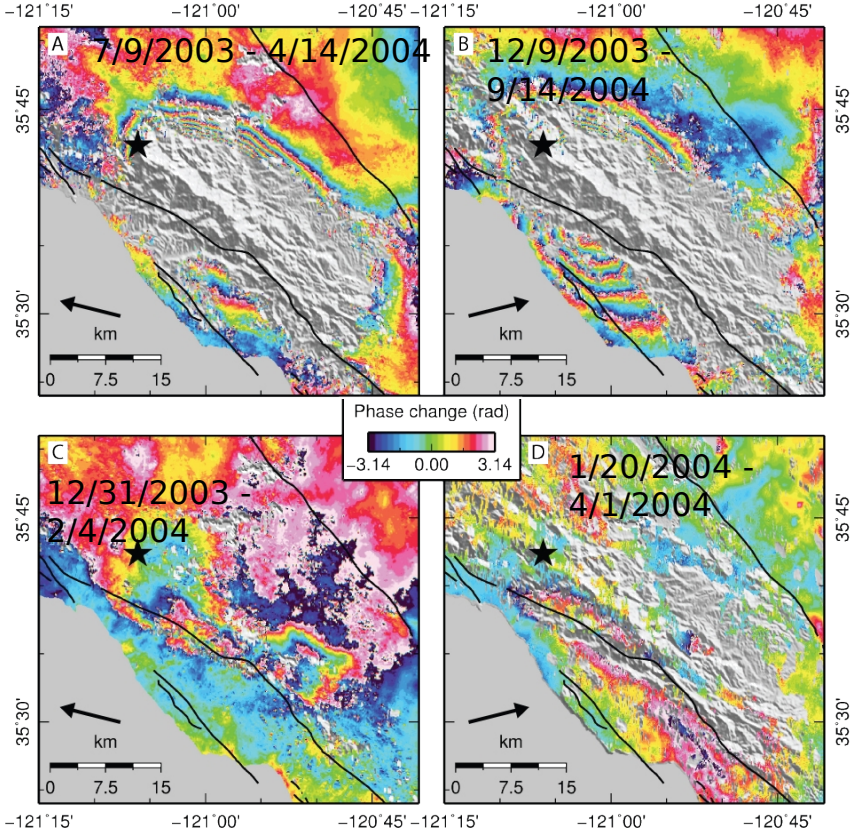
12/31/2003 - 2/4/2004
Descending ERS

1/20/2004 - 4/1/2004
Ascending Radarsat

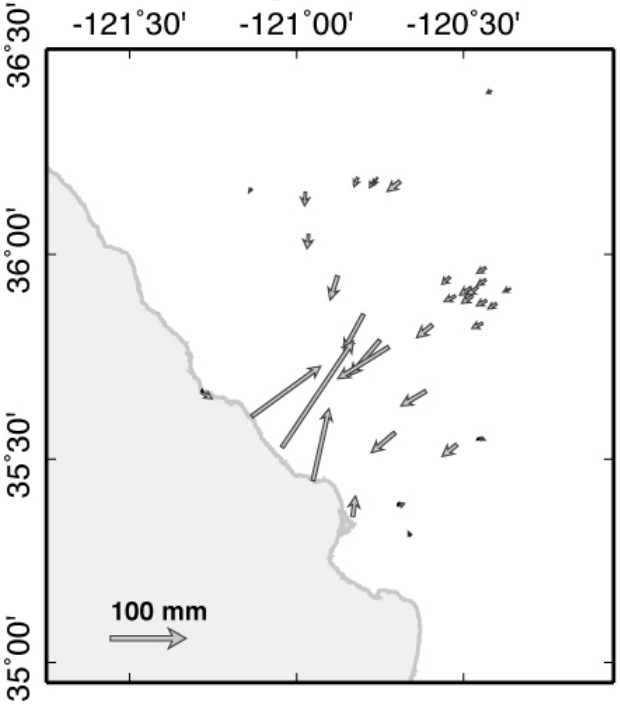
1 cycle = 2.8 cm

Geodetic Data for San Simeon EQ

- 4 Interferograms
  - Intermixed
  - Postseismic only
- 1 set GPS displacements
  - Coseismic only
- 1 model
  - BOTH co-, post- slip



Coseismic (d_{pk})



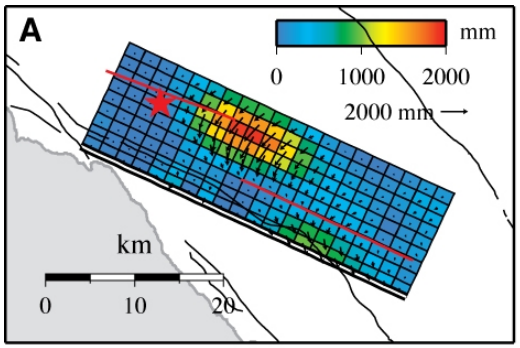
Inversion Formulation

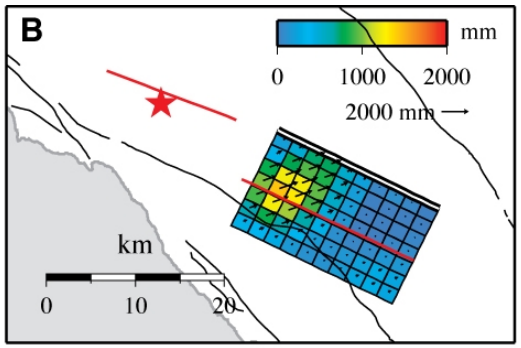
$$\begin{bmatrix} \mathbf{W}\mathbf{G} \\ \beta\nabla^2 \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{W}\mathbf{d} \\ \mathbf{0} \end{bmatrix} = \mathbf{m}$$

$$\mathbf{m} = \begin{bmatrix} \mathbf{s}_C \\ \mathbf{A}_{P1} \\ \mathbf{s}_{P2} \\ \mathbf{t} \end{bmatrix}$$

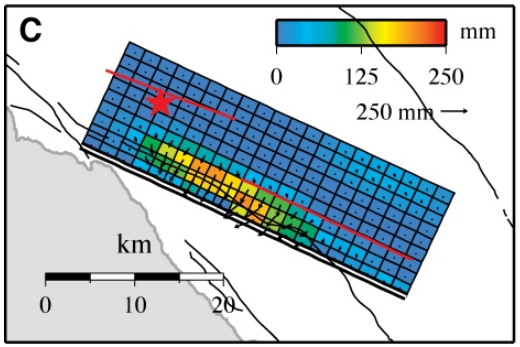
$$\mathbf{G} = \begin{bmatrix} \mathbf{G}_{Ca} & \mathbf{G}_{P1a}\left(1 - e^{-t_{a2}/\tau}\right) & \mathbf{G}_{P2a} & \mathbf{xy}_a \\ \mathbf{G}_{Cb} & \mathbf{G}_{P1b}\left(1 - e^{-t_{b2}/\tau}\right) & \mathbf{G}_{P2b} & \mathbf{xy}_b \\ \mathbf{0} & \mathbf{G}_{P1c}\left(e^{-t_{c1}/\tau} - e^{-t_{c2}/\tau}\right) & \mathbf{G}_{P2c} & \mathbf{xy}_c \\ \mathbf{0} & \mathbf{G}_{P1d}\left(e^{-t_{d1}/\tau} - e^{-t_{d2}/\tau}\right) & \mathbf{0} & \mathbf{xy}_d \\ \mathbf{G}_{Cgps} & \mathbf{0} & \mathbf{0} & \mathbf{0} \end{bmatrix}$$

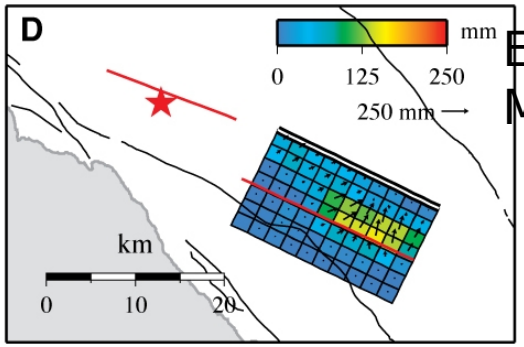
San Simeon Slip Model



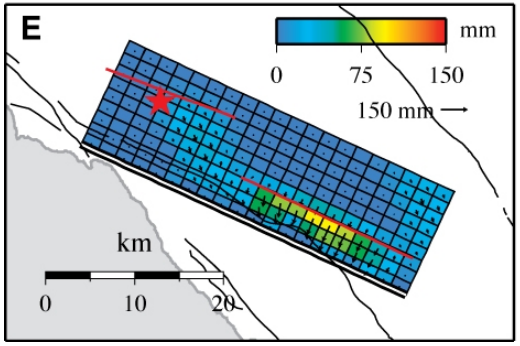


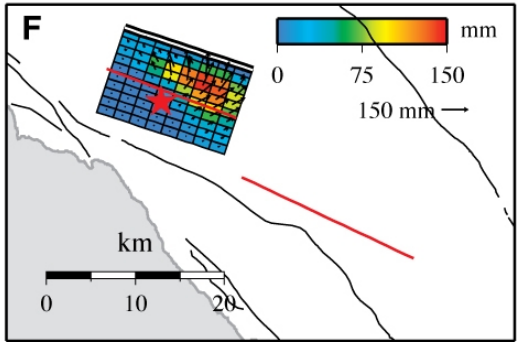
Coseismic Slip
M_w=6.5





Exponentially decaying slip
M_w=5.8 (9% of coseismic)

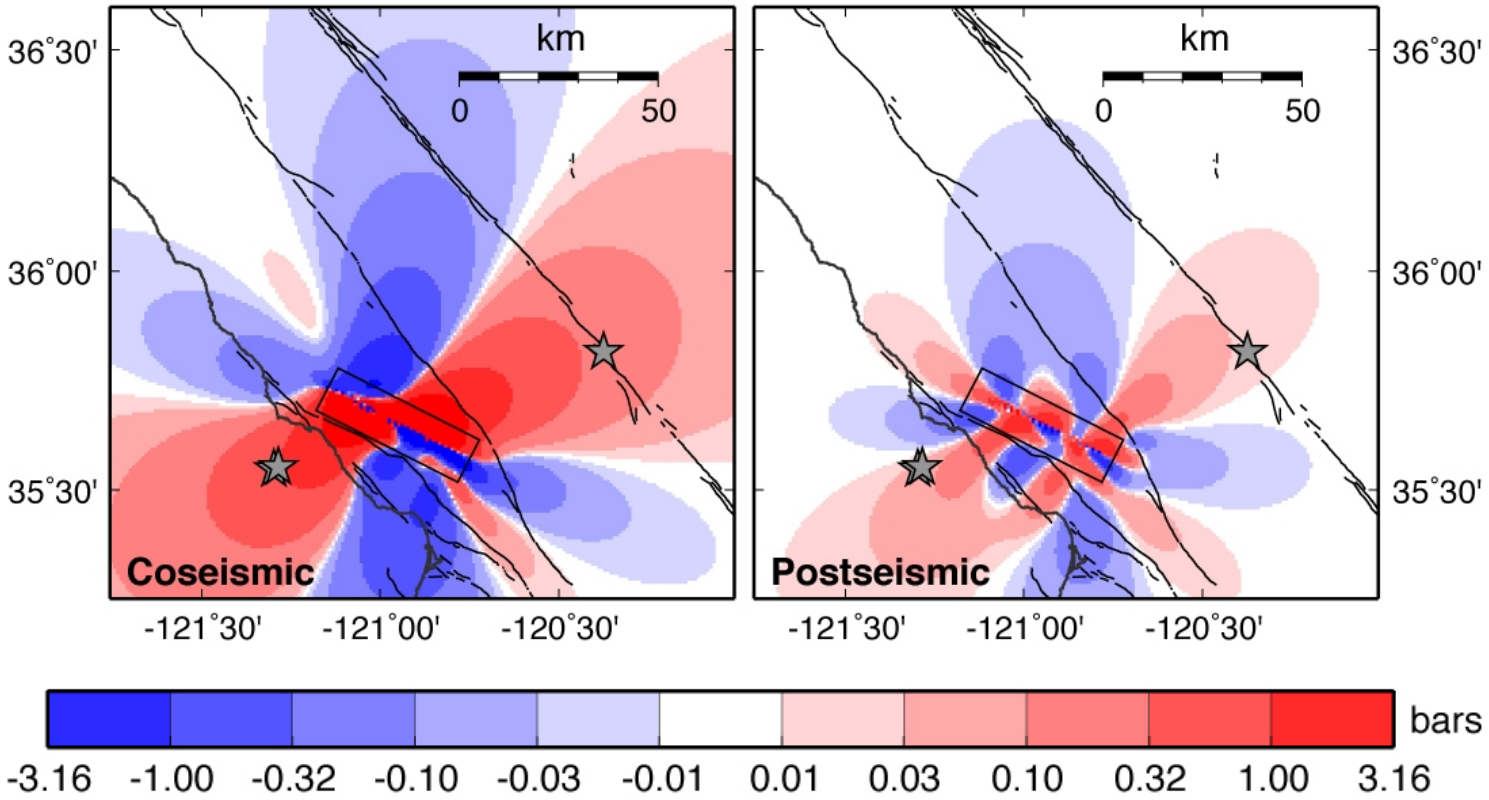




Extra slip
M_w=5.7 (5% coseismic)

ΔCoulomb Failure Stress
(San Andreas Parallel)

ΔCFS = μ´(normal stress) + (shear stress)
μ´=0.4 (from Toda and Stein, 2002)



0.1 bars is observed threshold for significant aftershock triggering (e.g.

Depth section at 8 km

Summary

- Coseismic and postseismic slip can be separated in the modeling stage in cases where
  - the data contains deformation from both periods
  - Some *a priori* info on the time history is available
- Doing so reveals important features of the EQ
  - Prevalence of aseismic slip relative to seismic
  - Distribution and decay of postseismic slip
  - Can calculate relative effects of each period on

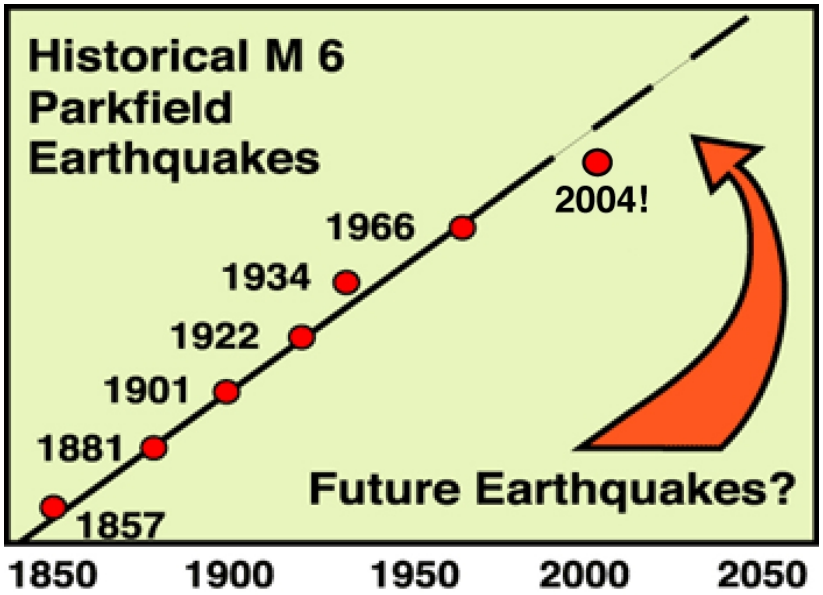
The Parkfield Earthquake Prediction Experiment

Quasi-regular series of M~6 earthquakes:

- Next was predicted for 1988 (Bakun & Lindh, 1985)
- earthquake occurred 16 years “late”

Goals:

- detect precursory slip
- test the characteristic earthquake hypothesis
- get the best records all aspects of an earthquake



http://quake.usgs.gov/research/parkfield

Fault Behavior Spectrum

Steinbrugge Collection, EERC, UC Berkeley

Some Creep

Some strain accumulation

"slow earthquakes"

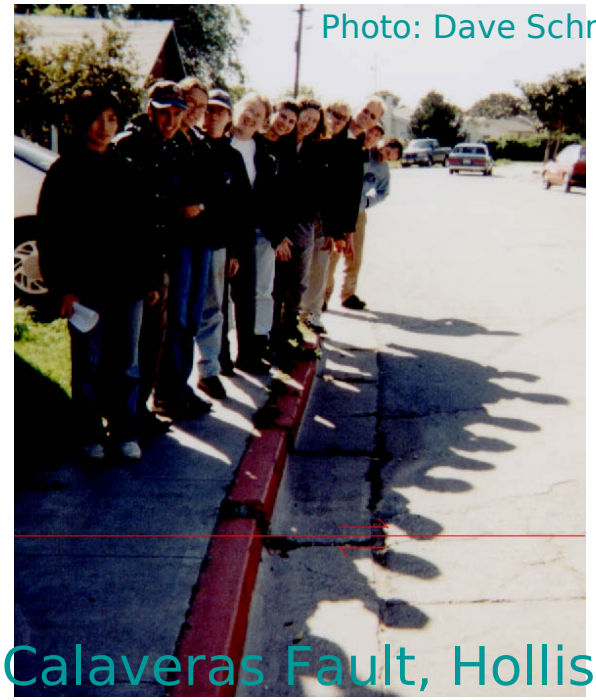


Photo: Dave Schmidt

Calaveras Fault, Hollister

Mixed Behavior

Locked Fault

Slip occurs primarily in large earthquakes

Transition Zone

Block offset

No strain accumulation

No large earthquakes

Key Observations

- Location at transition zone may control some of its behavior
  - Produces regular, similar earthquakes
  - Transient slip events, such as rapid postseismic slip
  - Sensitive to outside stresses.
- Stress decreased near 1966 hypocenter
  - 1983 Coalinga Earthquake (Toda and Stein, 2002)
  - 1993-1996 slow earthquake (Murray and Segall, 2005)
- Stress increased throughout Parkfield segment
  - 2003 San Simeon earthquake