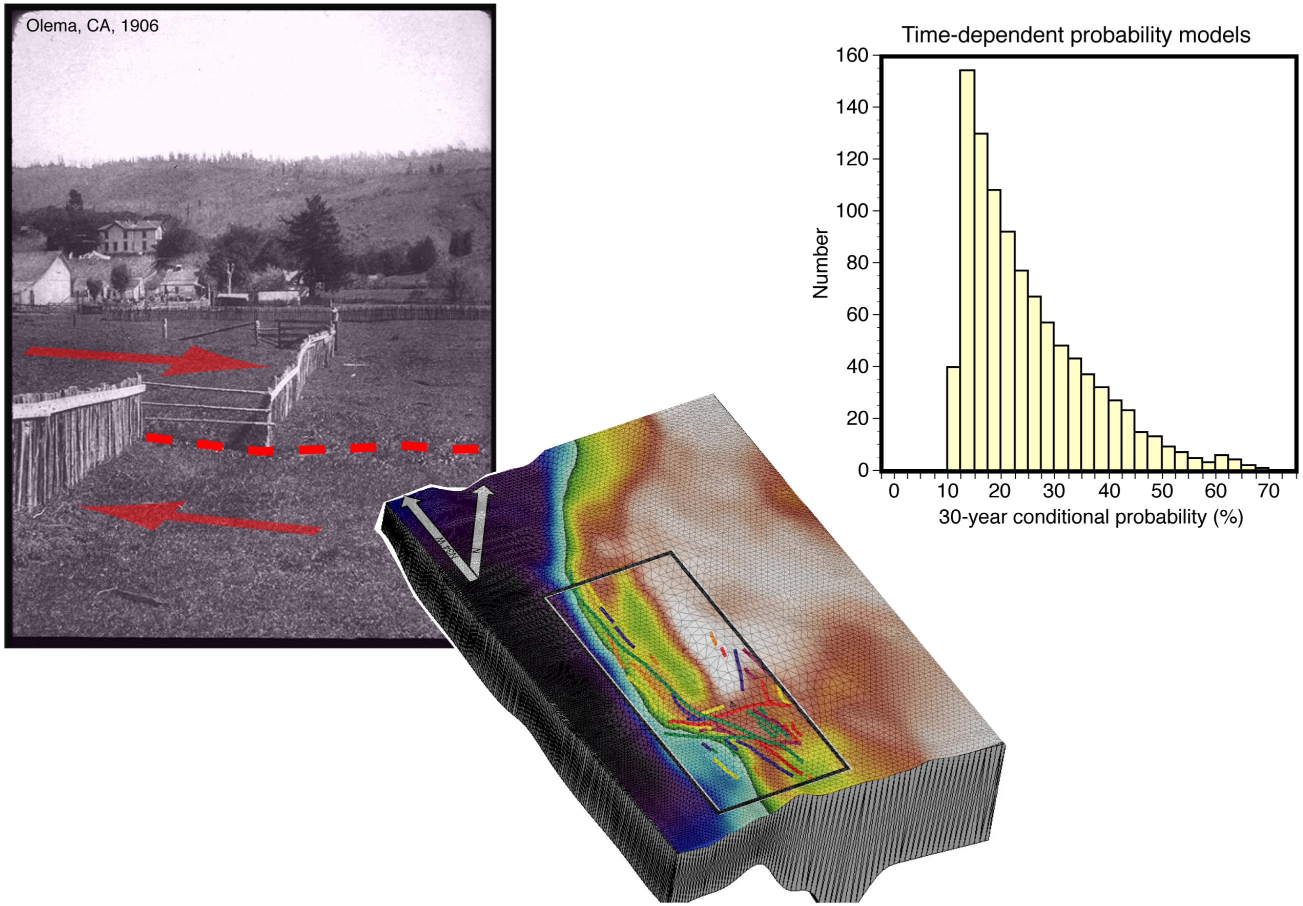
FEM and the next generation of California earthquake probability models



USGS
science for a changing world

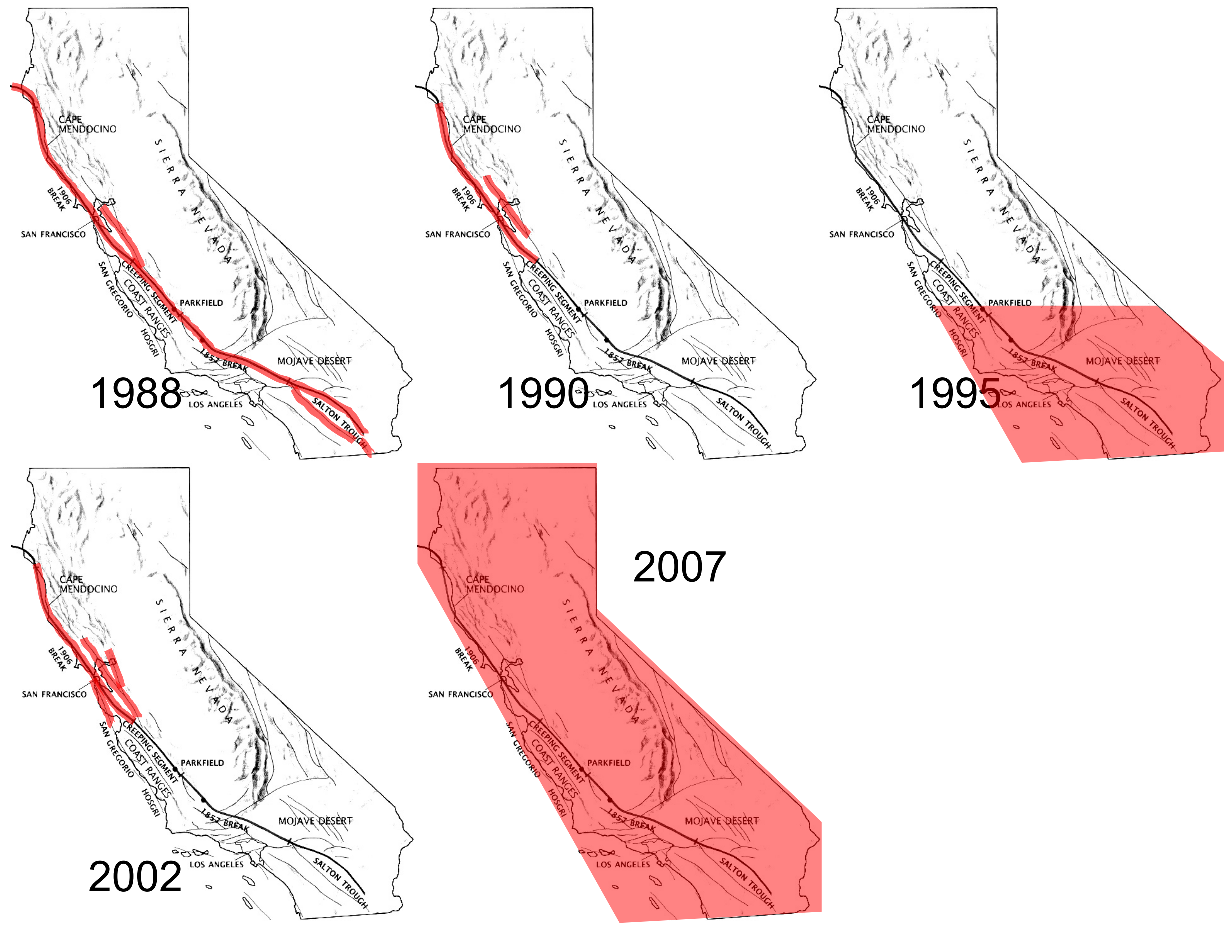
Uniform California Earthquake Rupture Forecast (UCERF) v. 2

- Time-independent rate model for National Seismic Hazard Map Program (NSHMP)
- Time-dependent probability calculation for California Earthquake Authority (CEA)

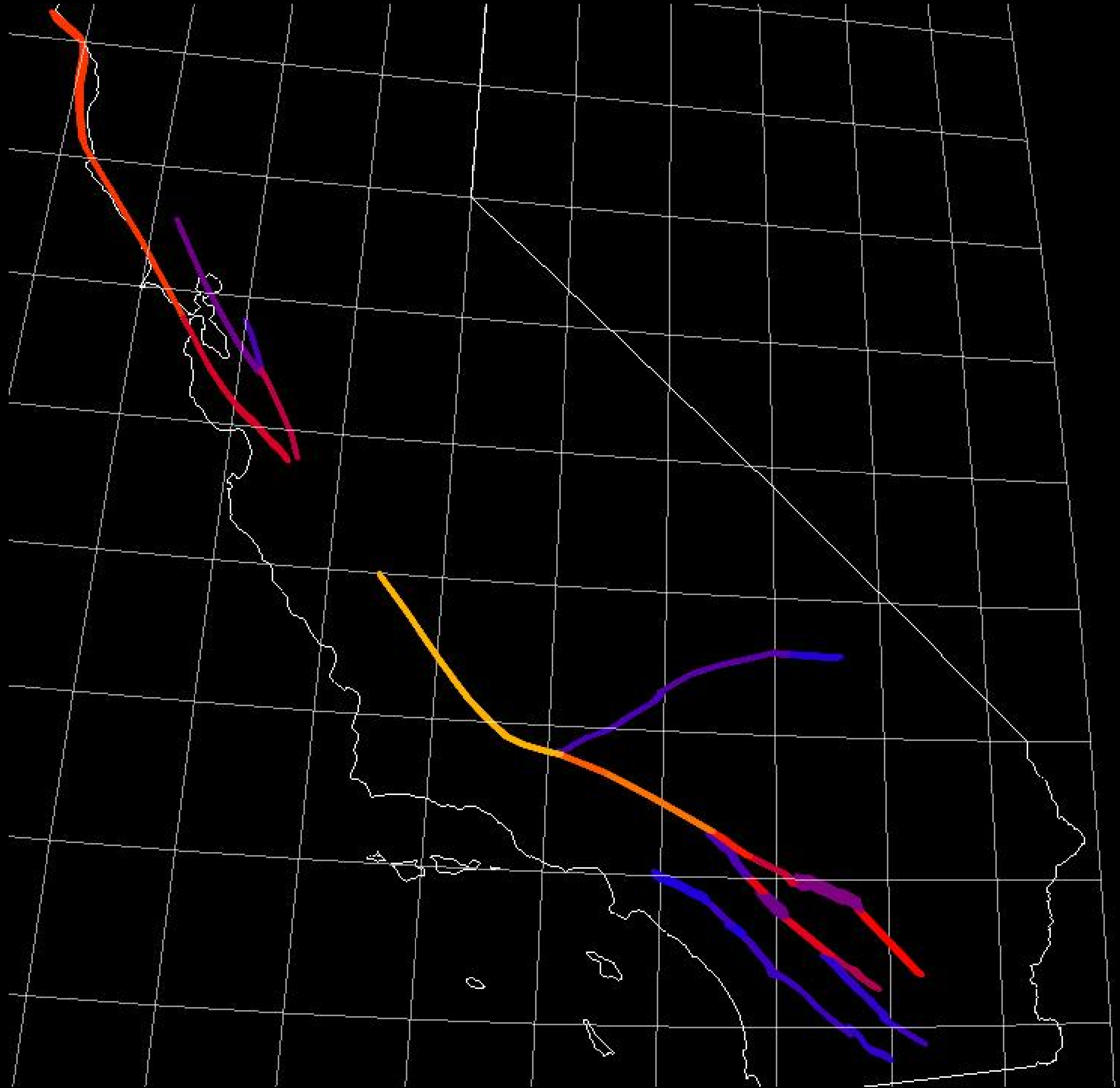
UCERF 3 = Optional alternative models, adds innovations

Statewide model

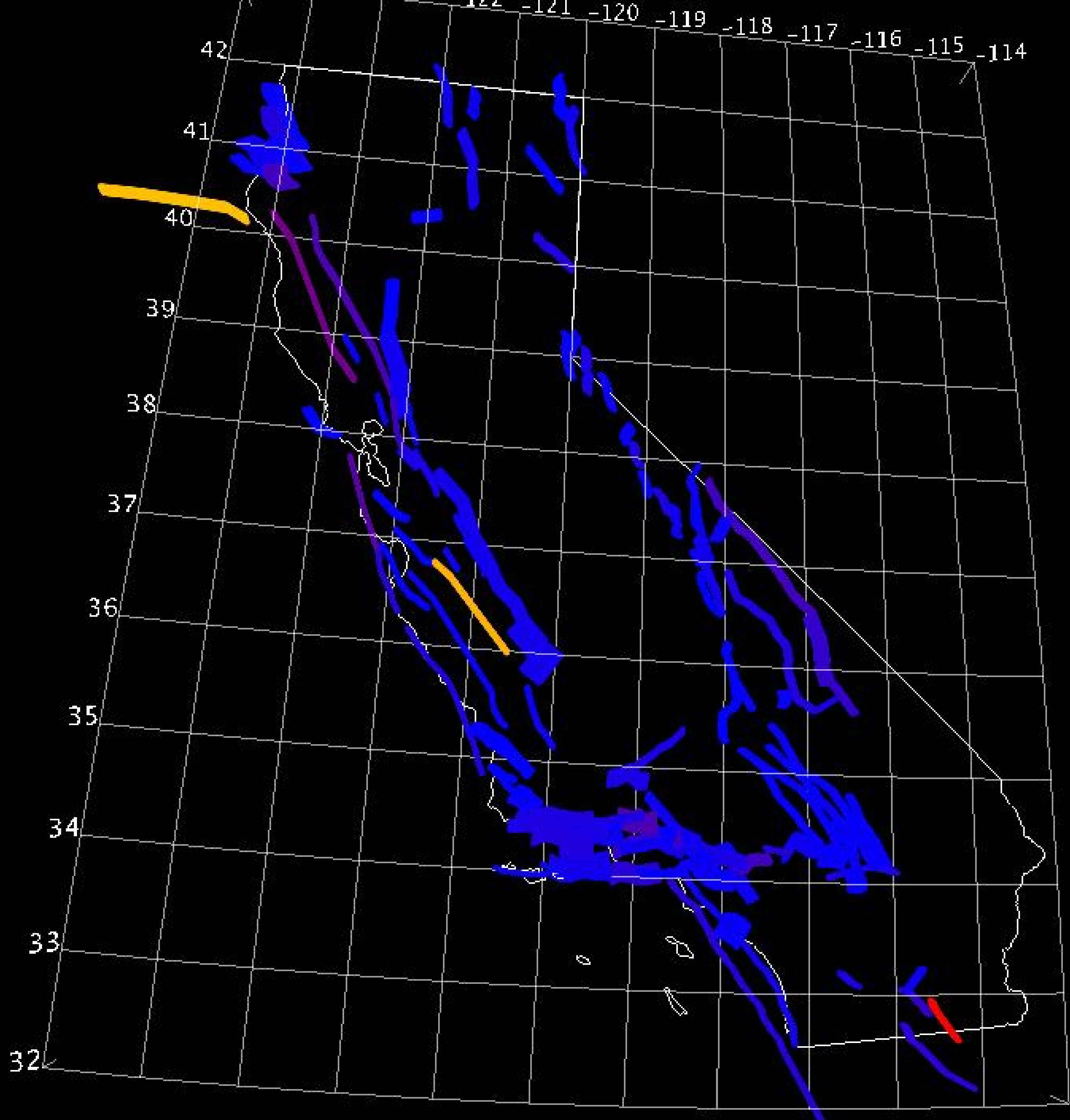
WGCEPs:



Type-A
Faults

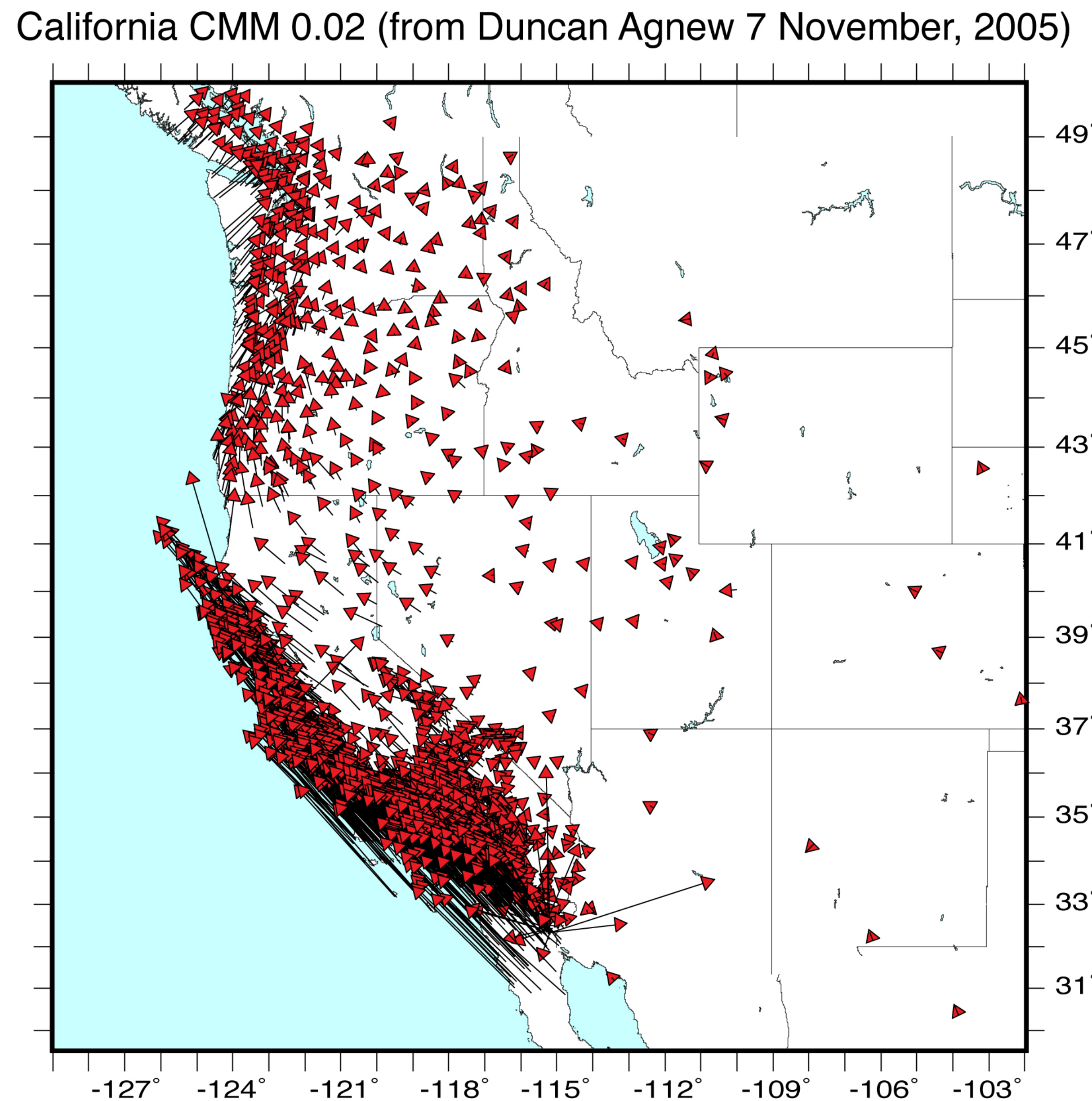


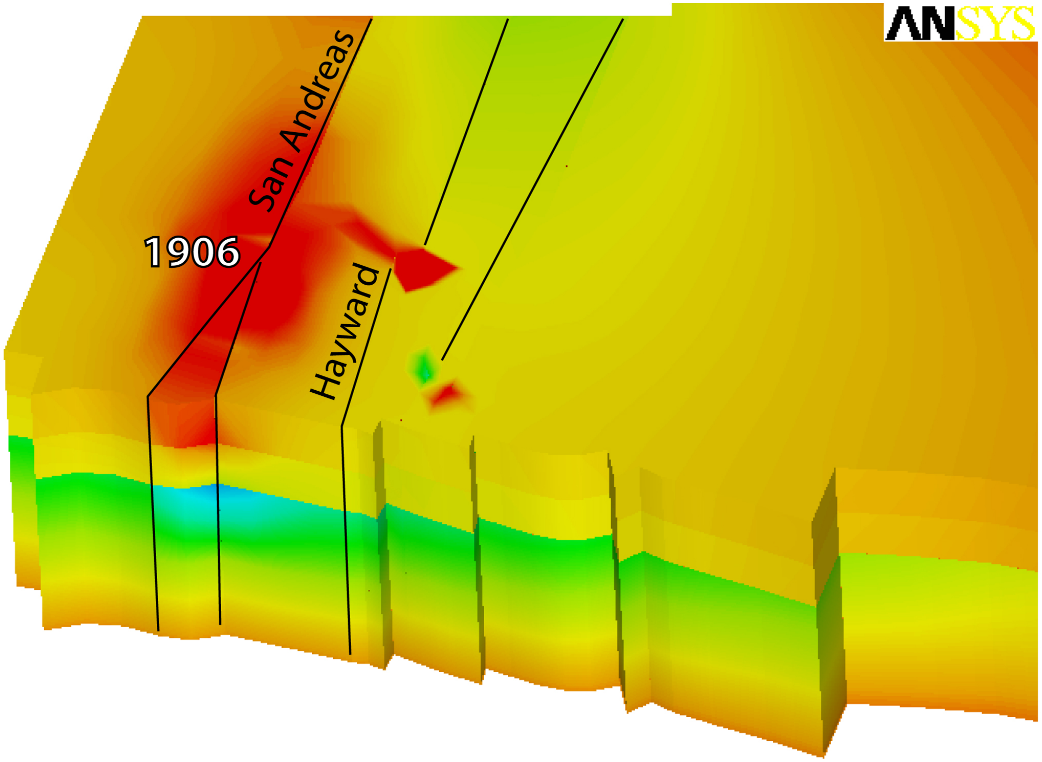
Type-B
Faults



Includes:
Updated CMM
SCIGN
BAVU
McCaffrey data
Murray data

All data are in a consistent North America reference frame





Post-seismic transient stress changes

From Working Group on California Earthquake Probabilities 2002 report:

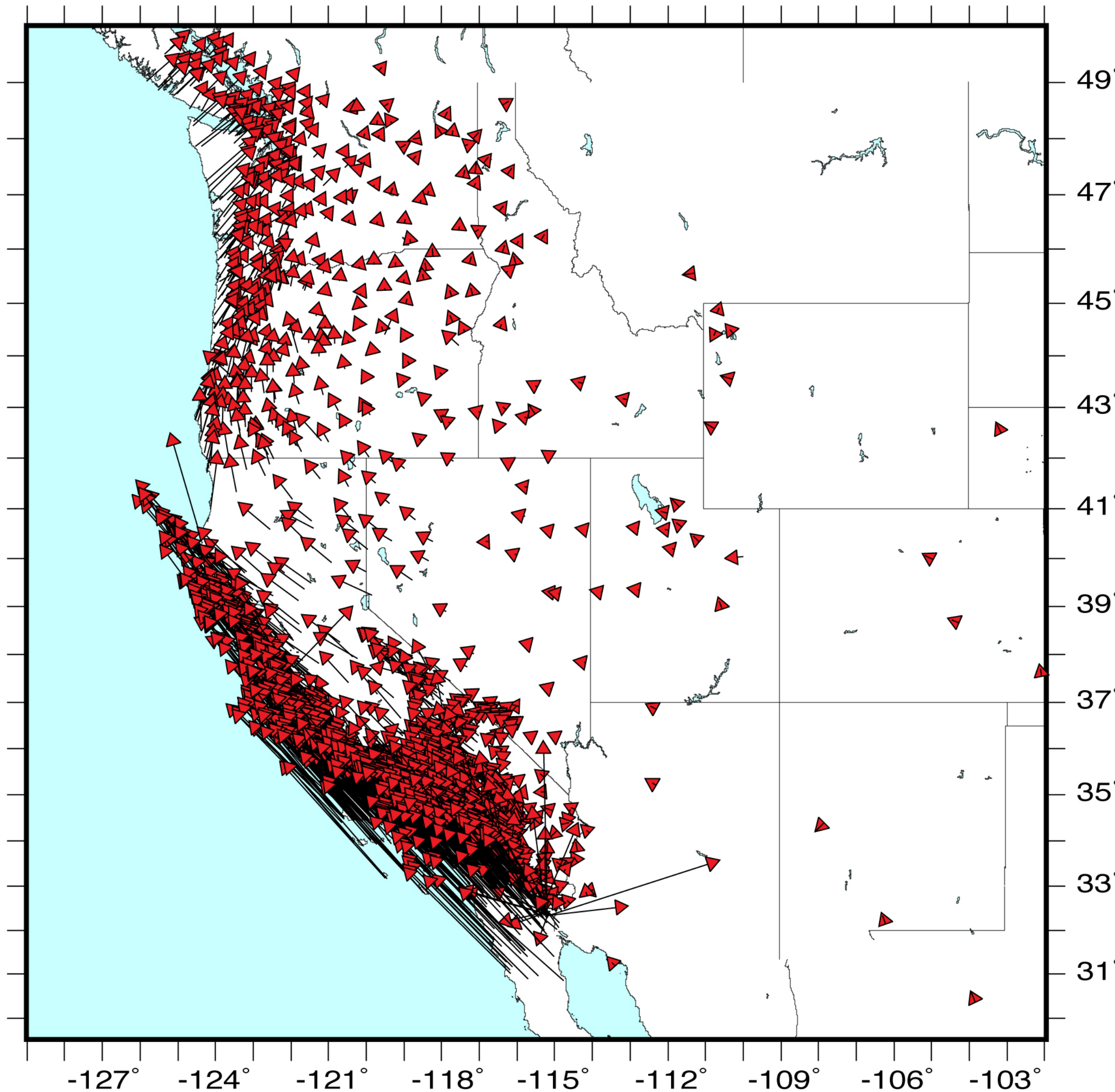
“We are aware that other methods (post-seismic viscoelastic stressing ...models) for calculating stress changes (and their effects) produced by the 1906 and 1989 earthquakes based on more complex physical processes are available (e.g., Kenner and Segall,1999; Parsons, 2002a; Pollitz et al., 1998).

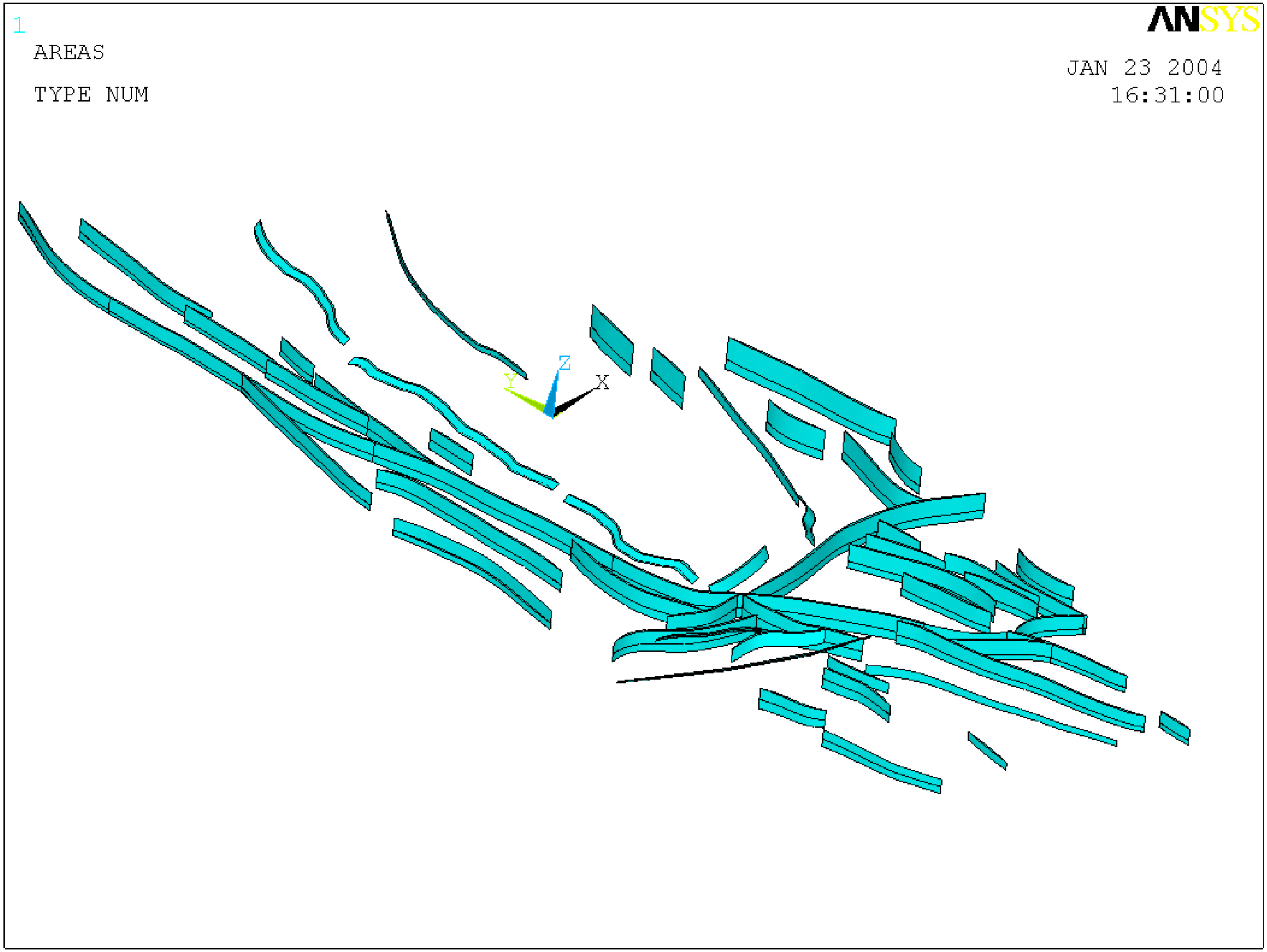
However, these models were considered by their authors and by the WG02 Oversight Committee to be insufficiently vetted for incorporation into the current SFBR probability calculations.”

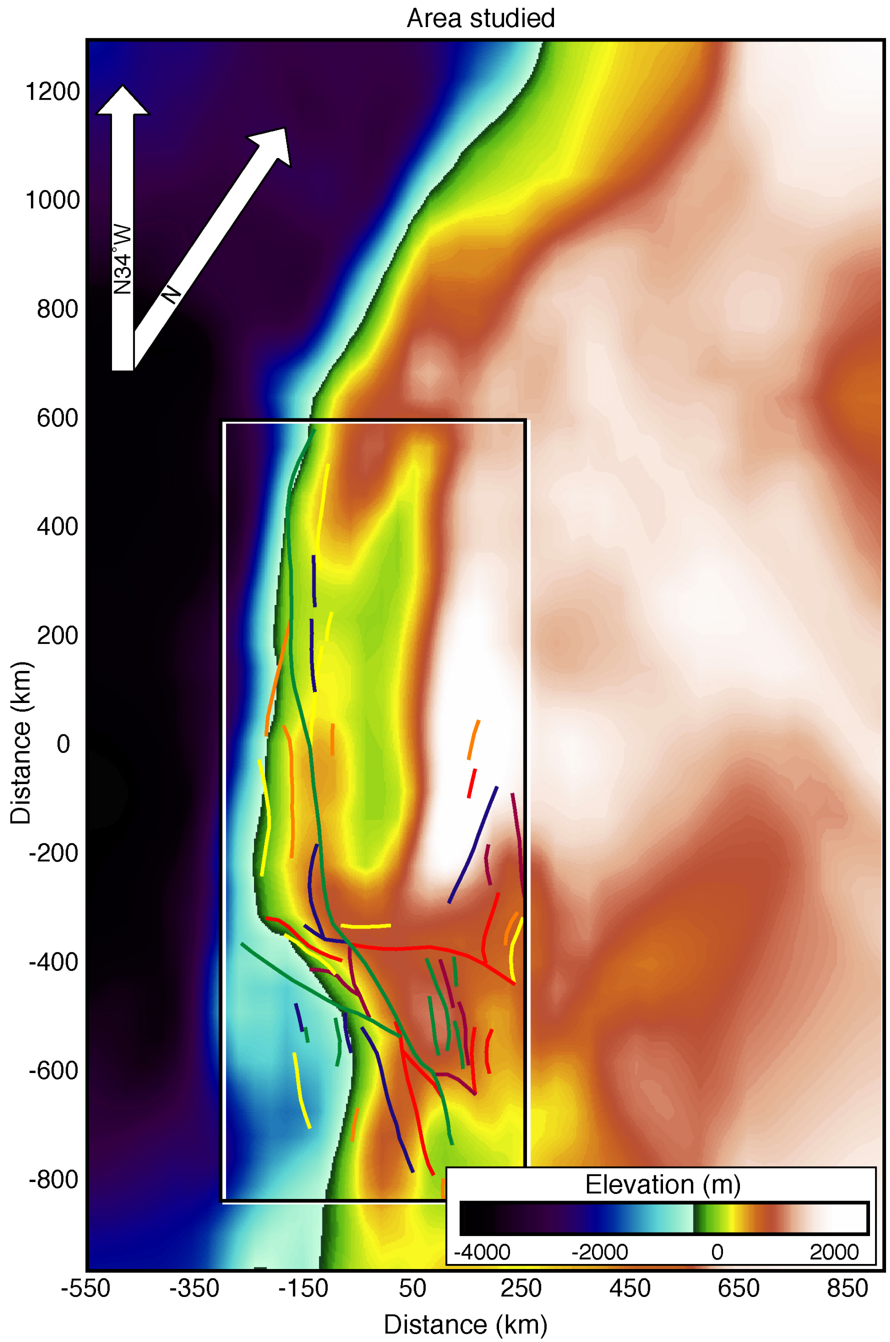
Includes:
Updated CMM
SCIGN
BAVU
McCaffrey data
Murray data

All data are in a consistent North America reference frame

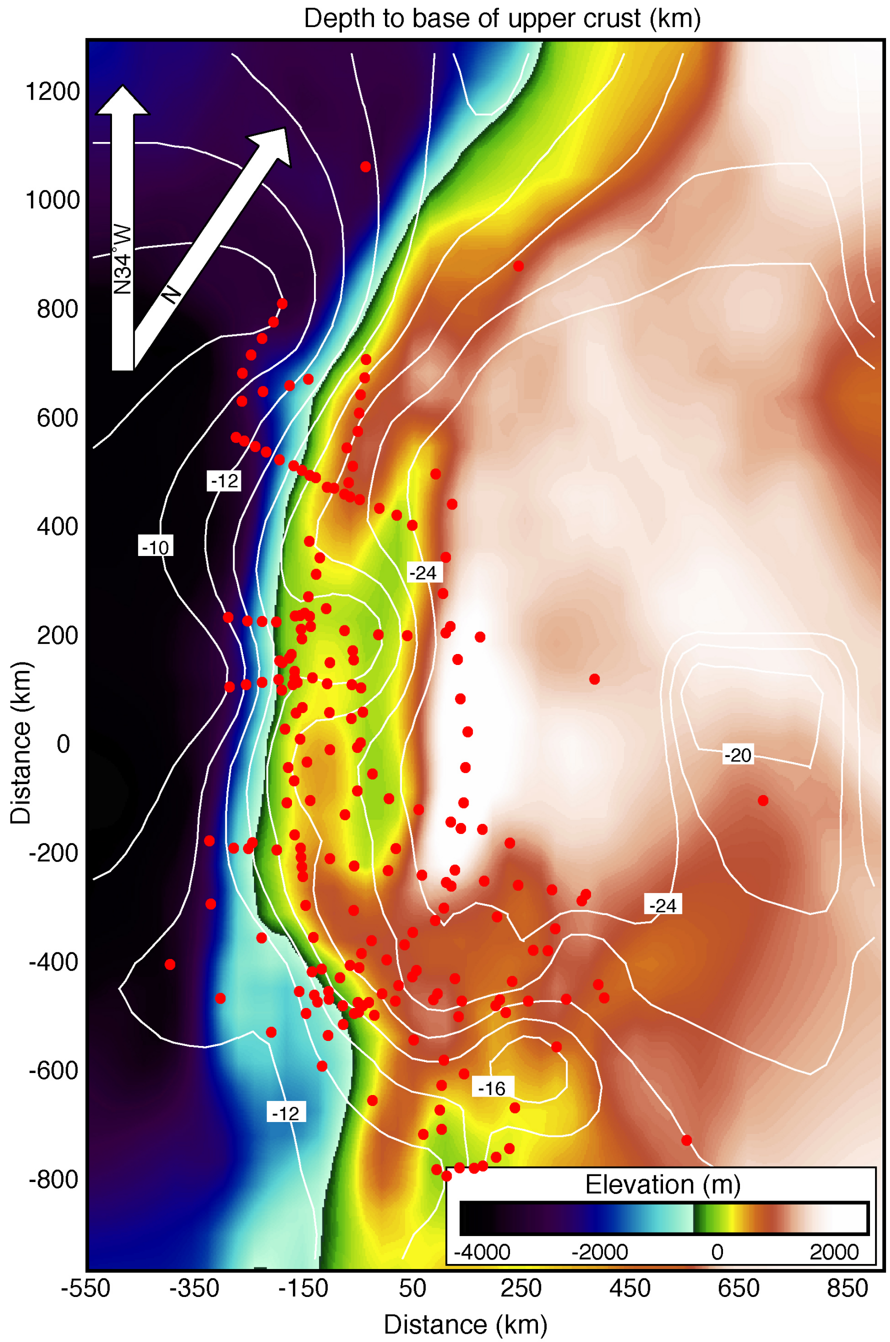
California CMM 0.02 (from Duncan Agnew 7 November, 2005)

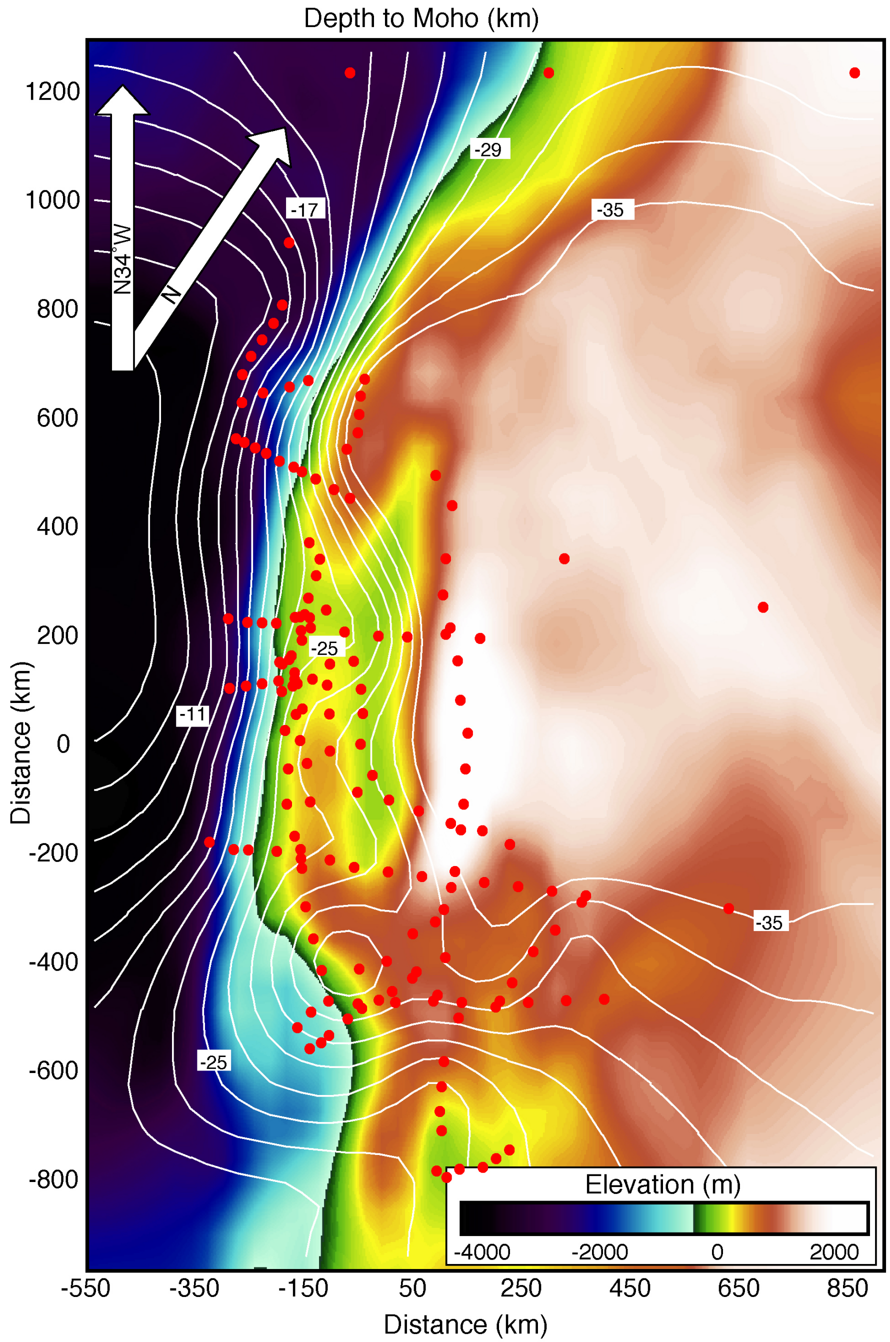



1
AREAS
TYPE NUM
ANSYS
JAN 23 2004
16:31:00
Y
Z
X

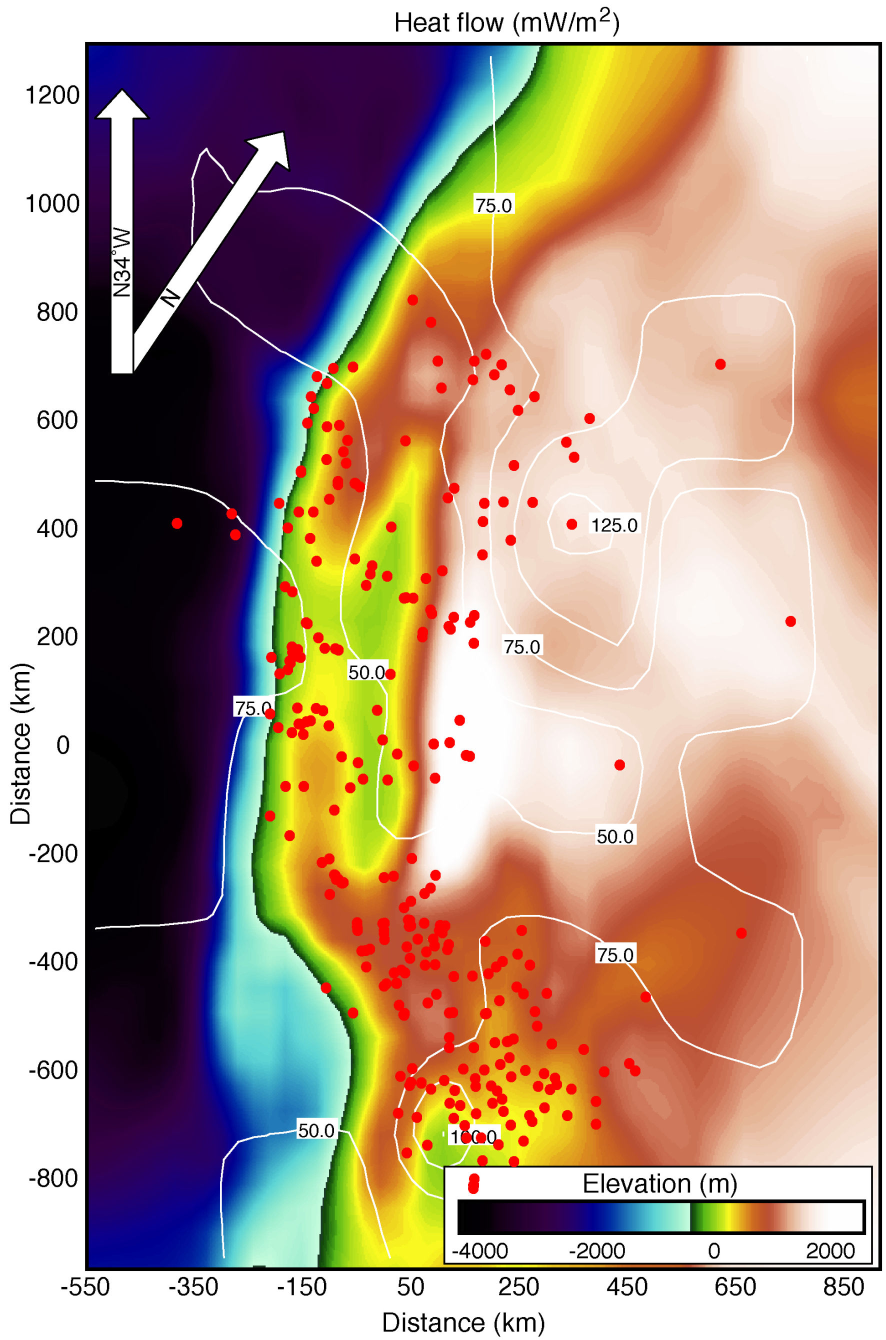


Area studied
N34°W
N
Elevation (m)
-4000
-2000
0
2000
Distance (km)
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-550
-350
-150
50
250
450
650
850
Distance (km)

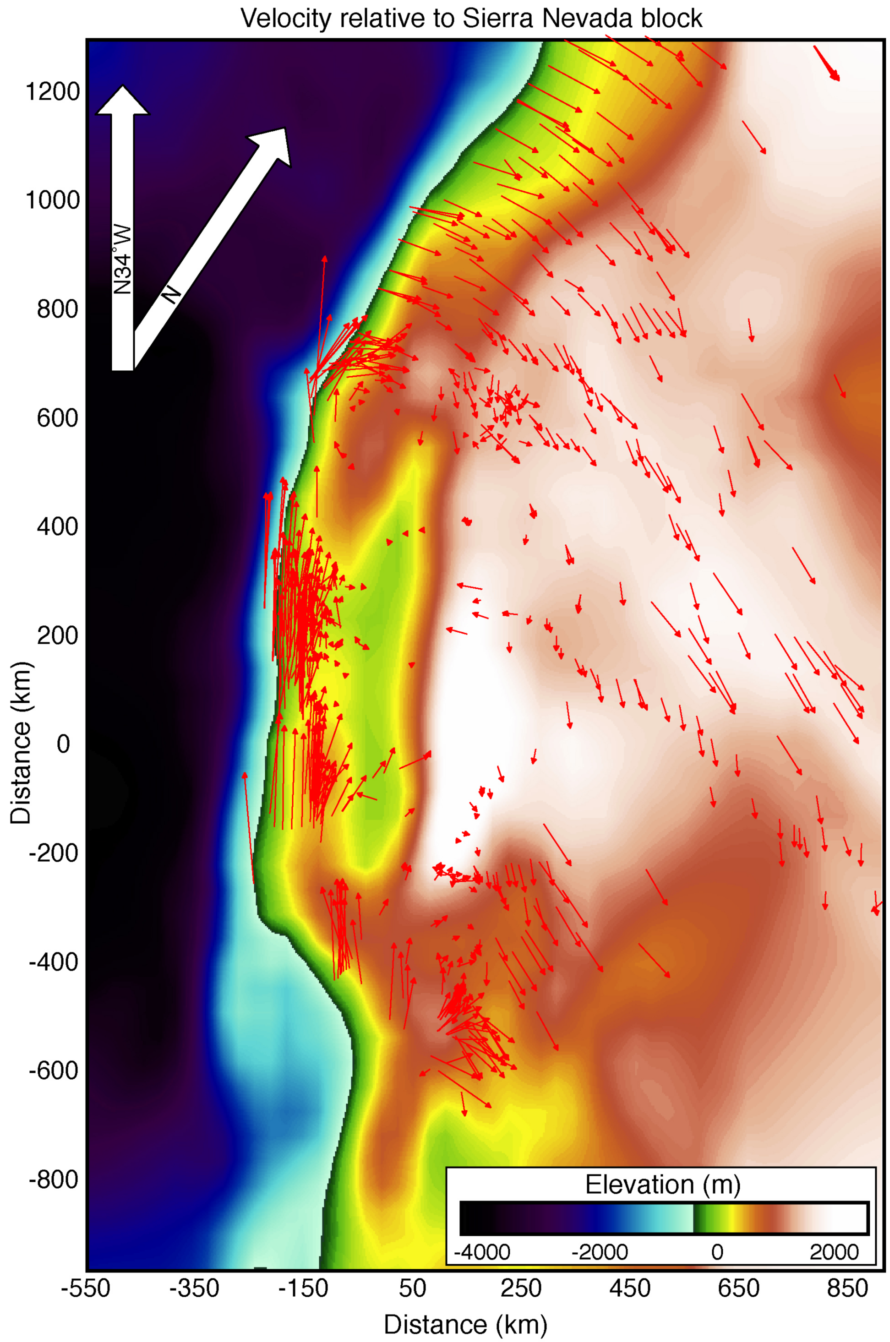

Depth to base of upper crust (km)
N34°W
N
-12
-10
-24
-20
-24
-16
-12
Elevation (m)
-4000
-2000
0
2000
1200
1000
800
600
400
200
0
-200
-400
-600
-800
Distance (km)
-550
-350
-150
50
250
450
650
850
Distance (km)



Depth to Moho (km)
N34˚W
N
-17
-29
-35
-25
-11
-25
-35
Elevation (m)
-4000
-2000
0
2000
1200
1000
800
600
400
200
0
-200
-400
-600
-800
Distance (km)
-550
-350
-150
50
250
450
650
850
Distance (km)

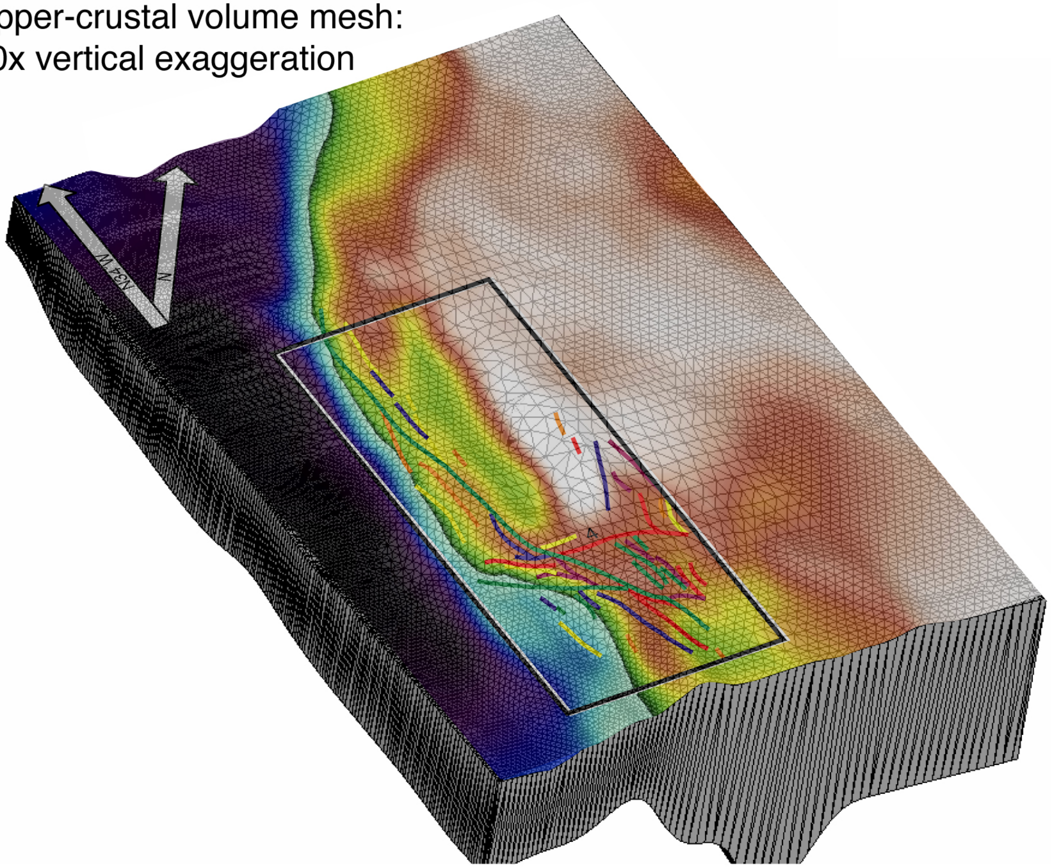


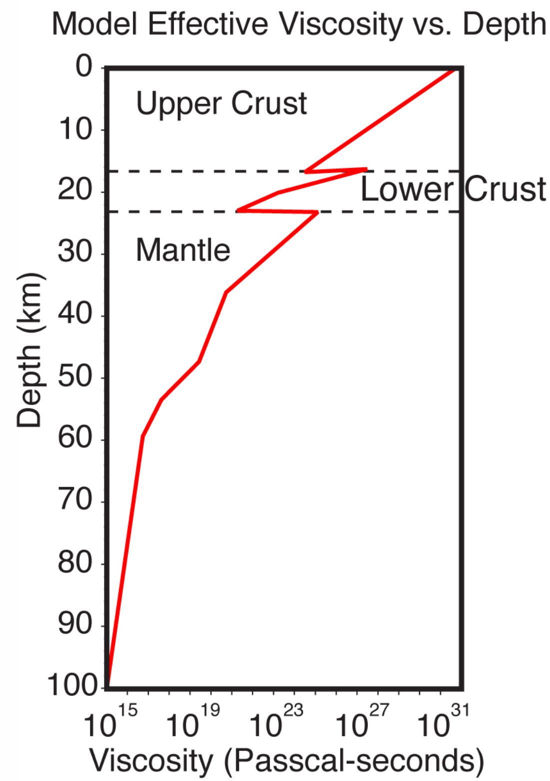
Heat flow (mW/m2)
1200
1000
800
600
400
200
0
-200
-400
-600
-800
Distance (km)
-550
-350
-150
50
250
450
650
850
Distance (km)
N34°W
N
75.0
125.0
75.0
50.0
75.0
50.0
75.0
50.0
100.0
Elevation (m)
-4000
-2000
0
2000


Velocity relative to Sierra Nevada block
N34°W
N
Elevation (m)
-4000
-2000
0
2000
1200
1000
800
600
400
200
0
-200
-400
-600
-800
Distance (km)
-550
-350
-150
50
250
450
650
850
Distance (km)

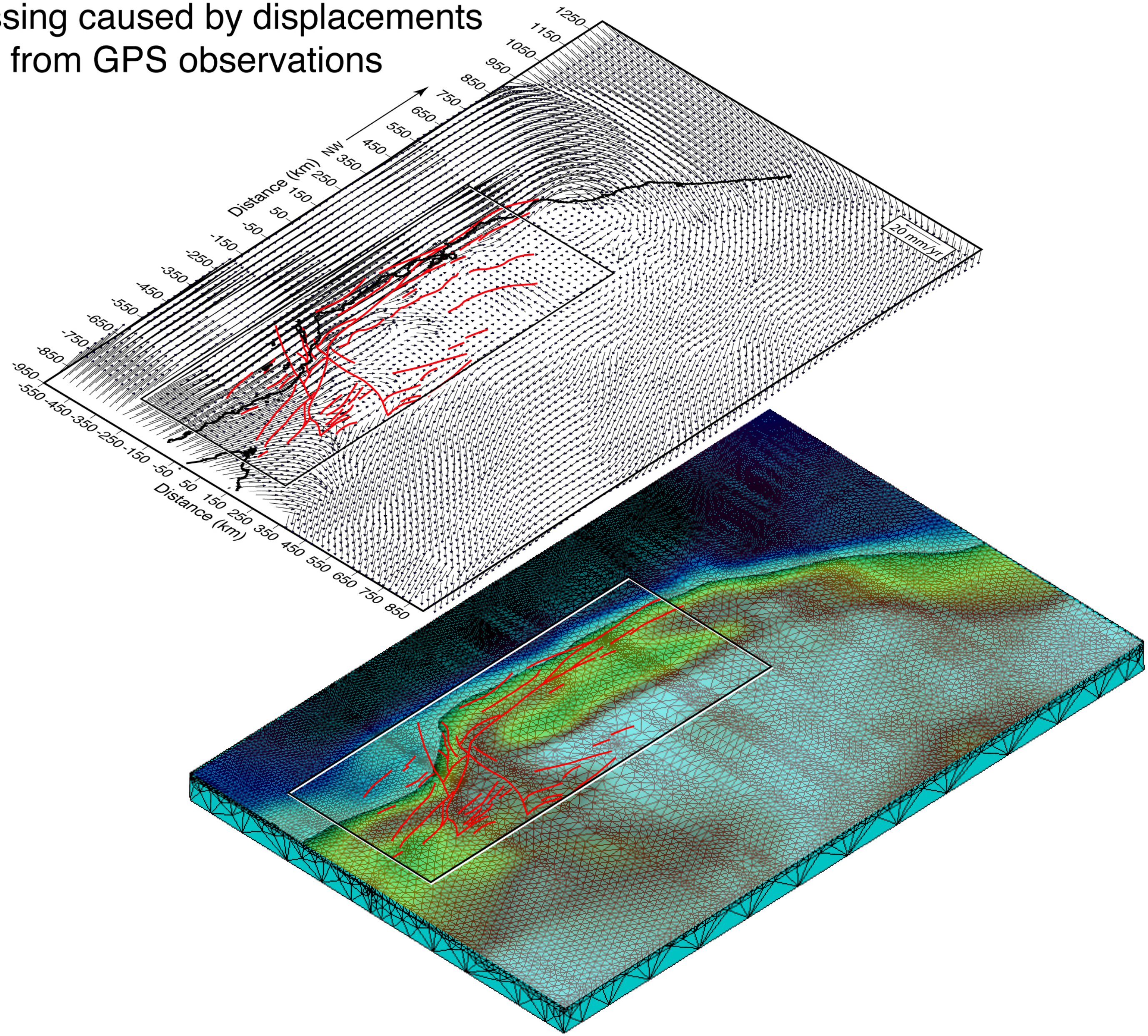
California finite elment model with topographic loading, variable crustal and mantle lithosphere thickness, and variable thermal rheology

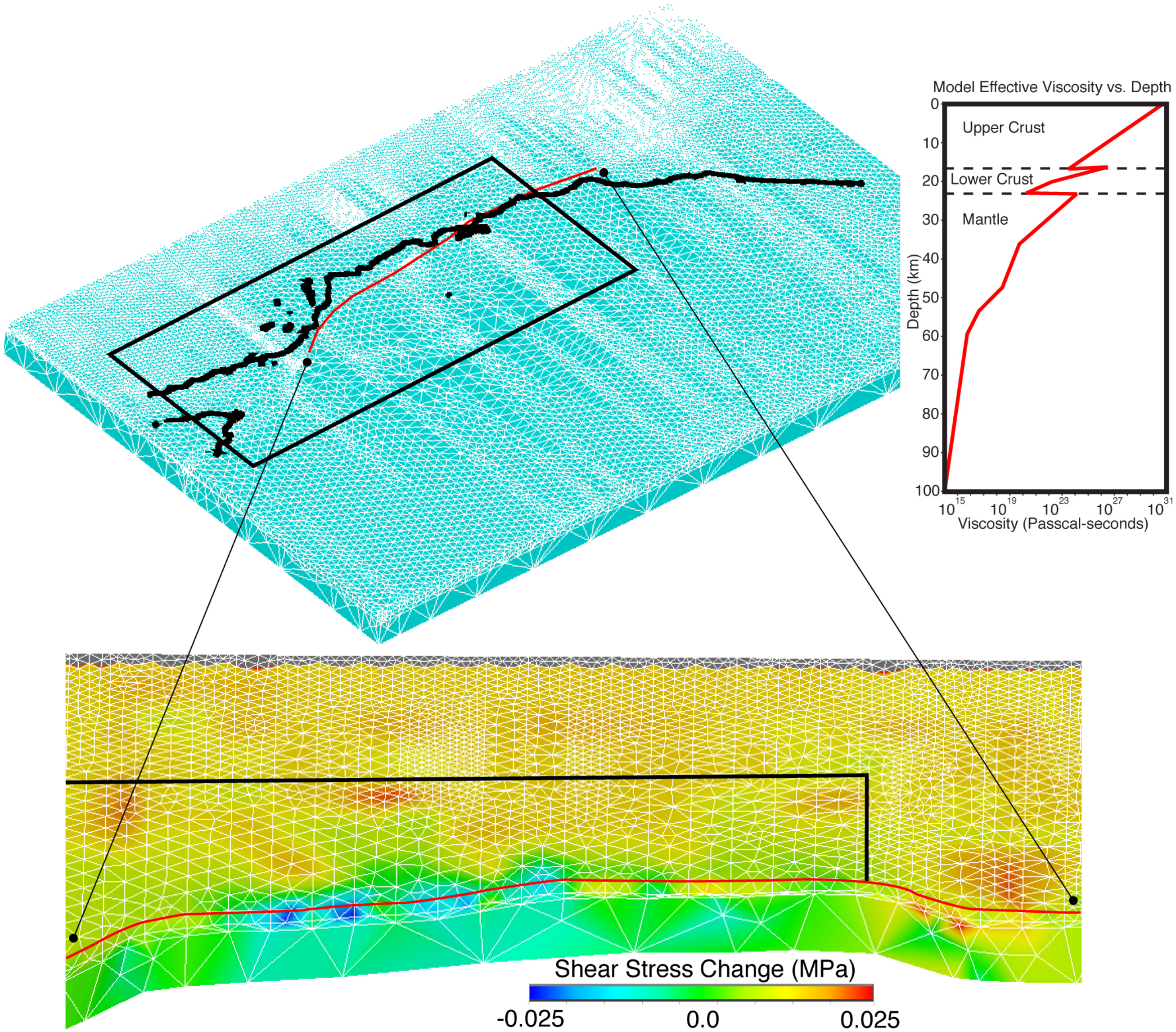
Upper-crustal volume mesh:
10x vertical exaggeration





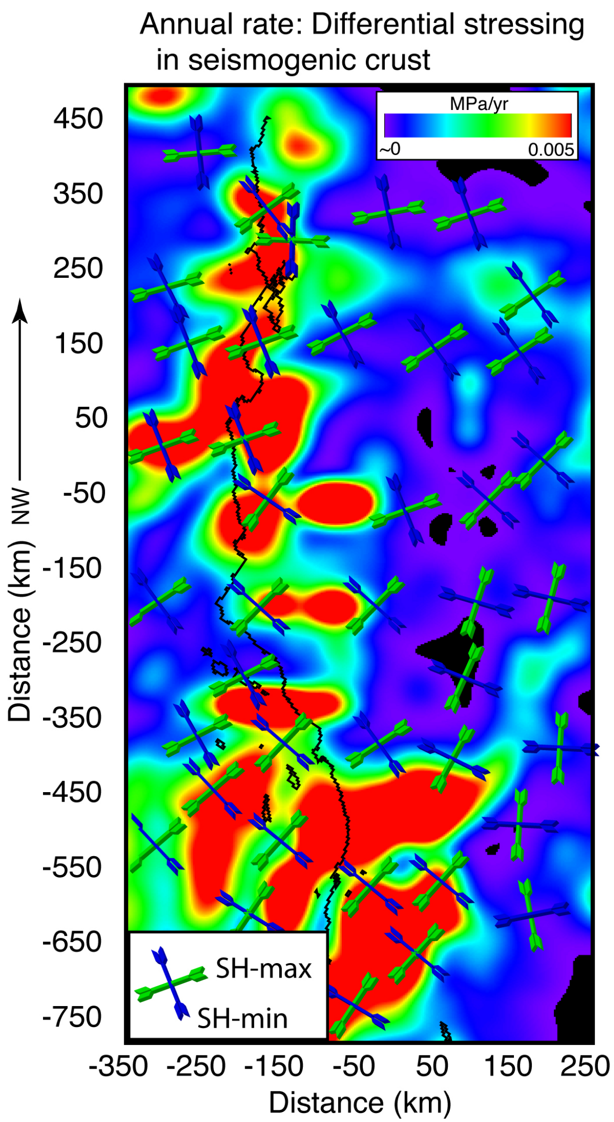
Crustal stressing caused by displacements interprolated from GPS observations

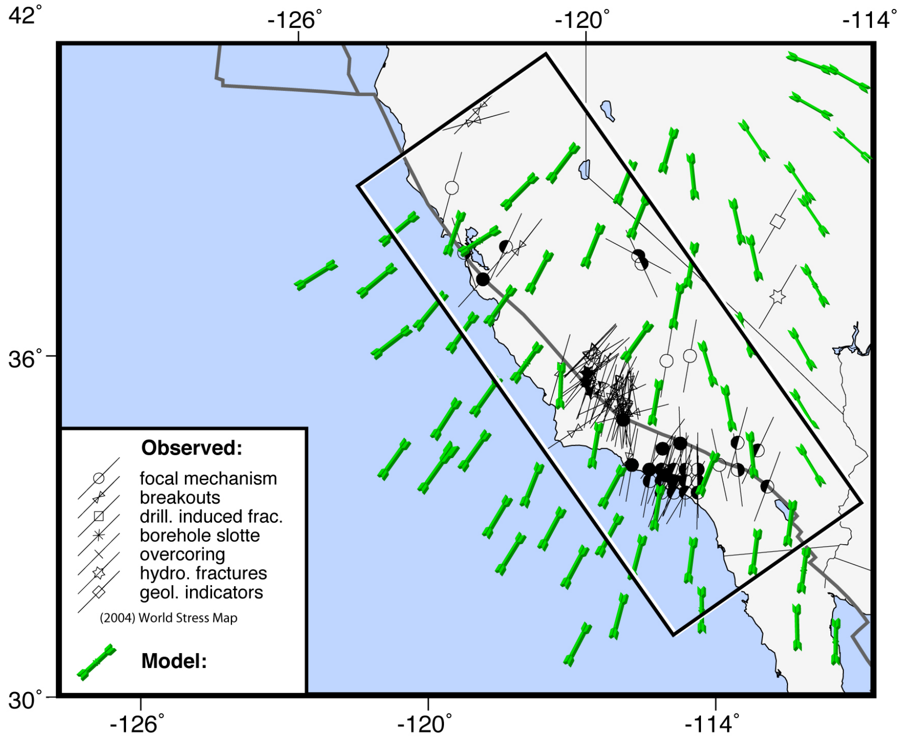




Model Effective Viscosity vs. Depth
Upper Crust
Lower Crust
Mantle
Depth (km)
0
10
20
30
40
50
60
70
80
90
100
10^{15}
10^{19}
10^{23}
10^{27}
10^{31}
Viscosity (Passcal-seconds)
Shear Stress Change (MPa)
-0.025
0.0
0.025

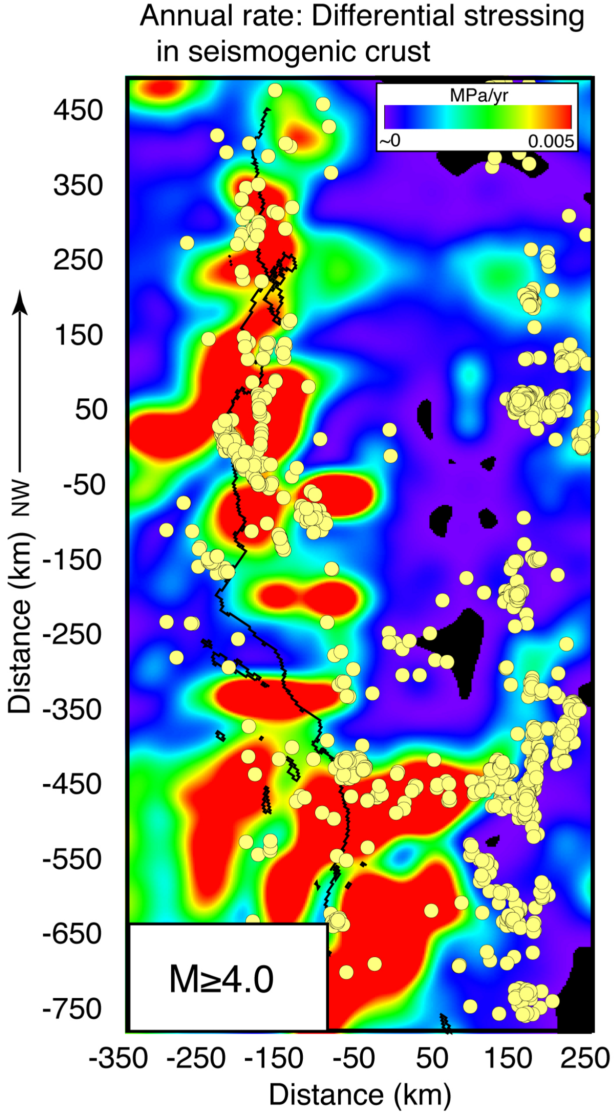
Variable stress orientations and rates calculated for San Andreas fault



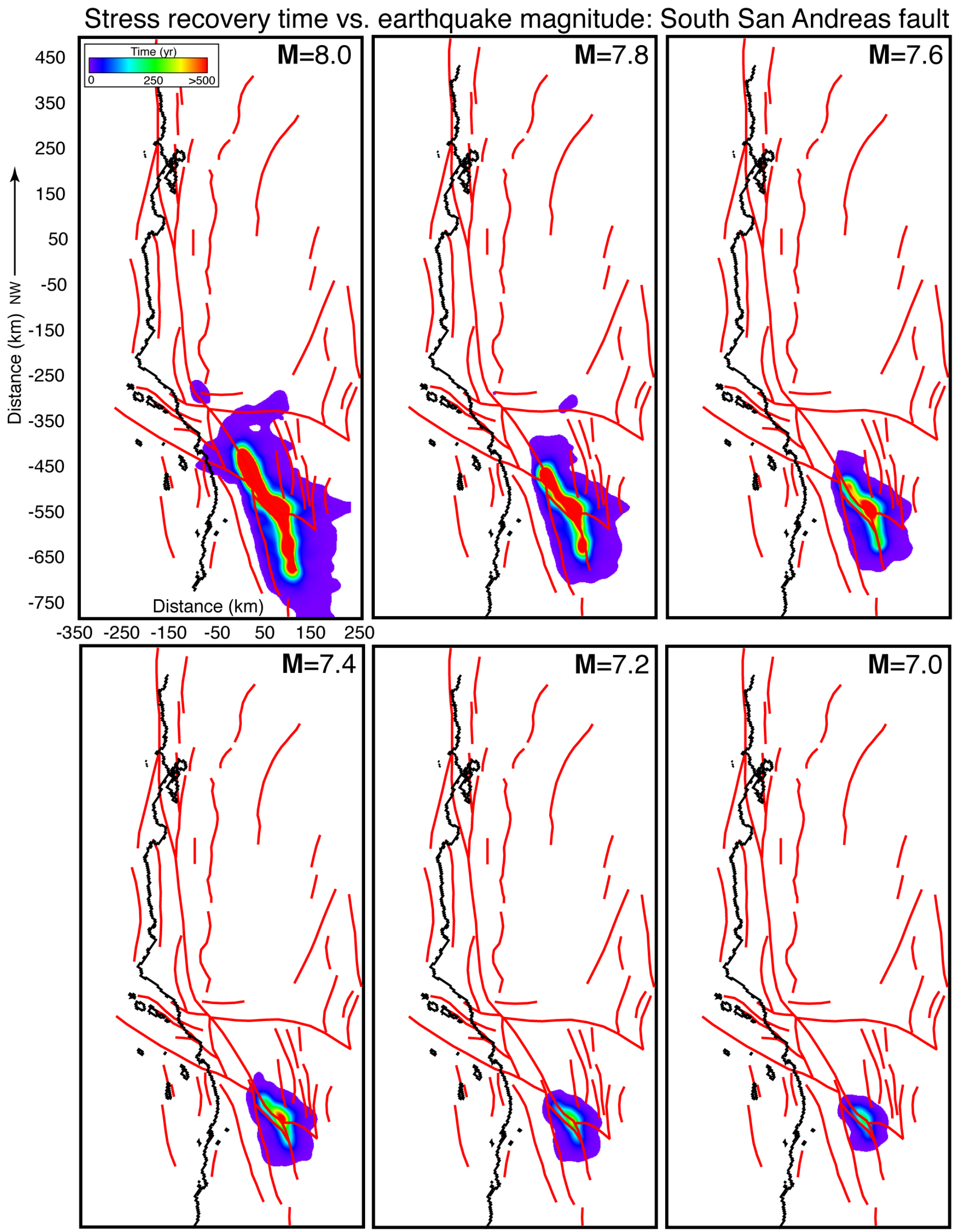


Model stress directions consistent with observed

Variable stress orientations and rates calculated for San Andreas fault

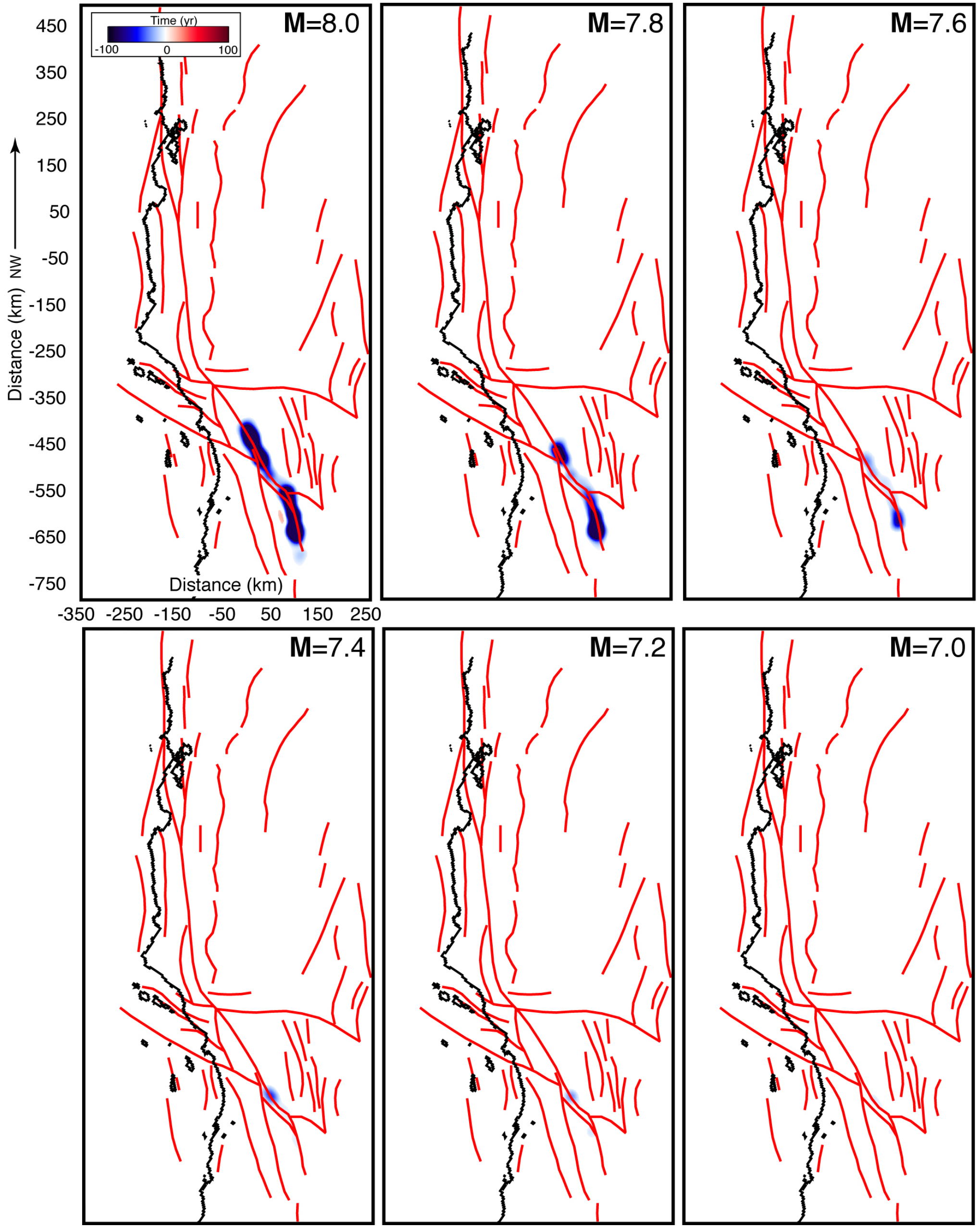


Seismicity is rare where low stressing rates are claculated



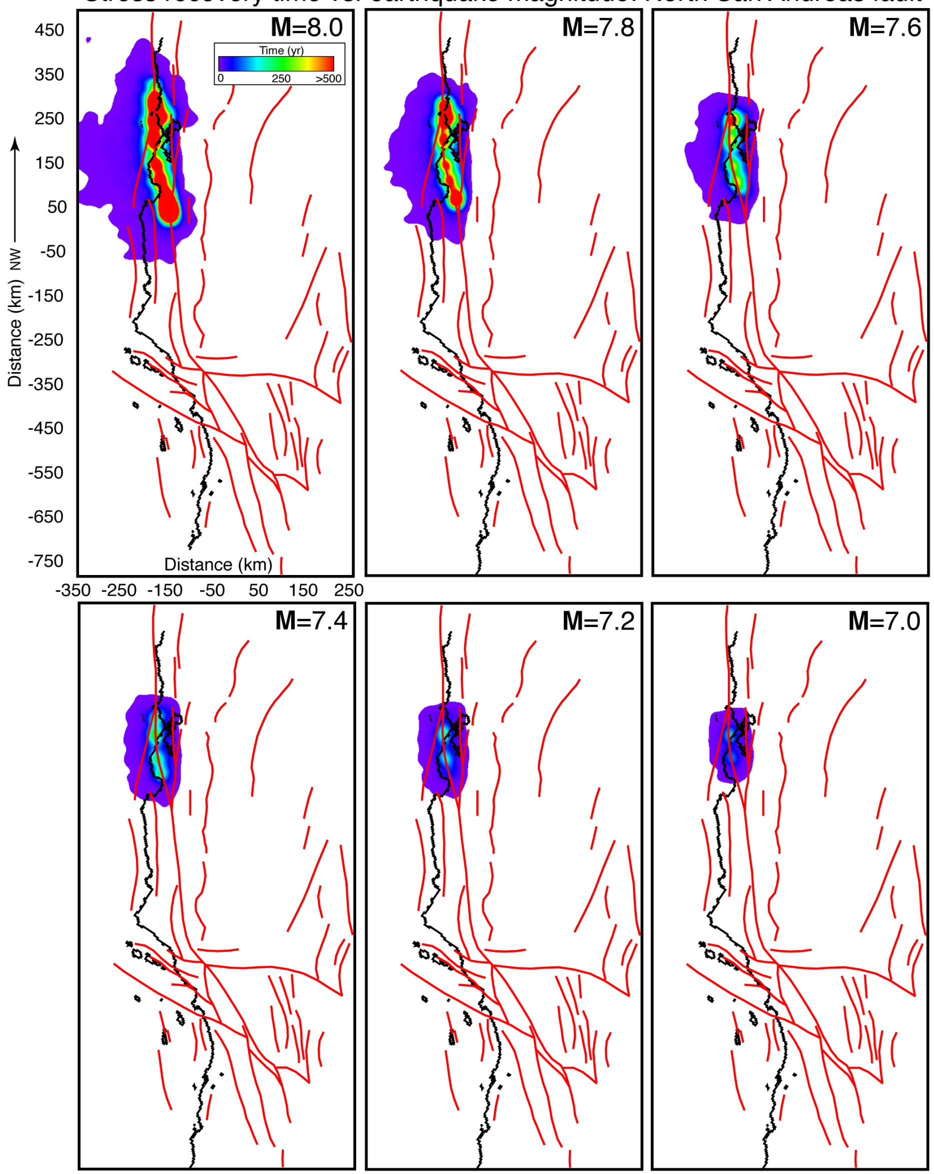
Scenario San Andreas earthquakes show complex stress recovery times vs magnitude and location

Post-seismic influence on stress recovery vs. earthquake magnitude: South San Andreas fault

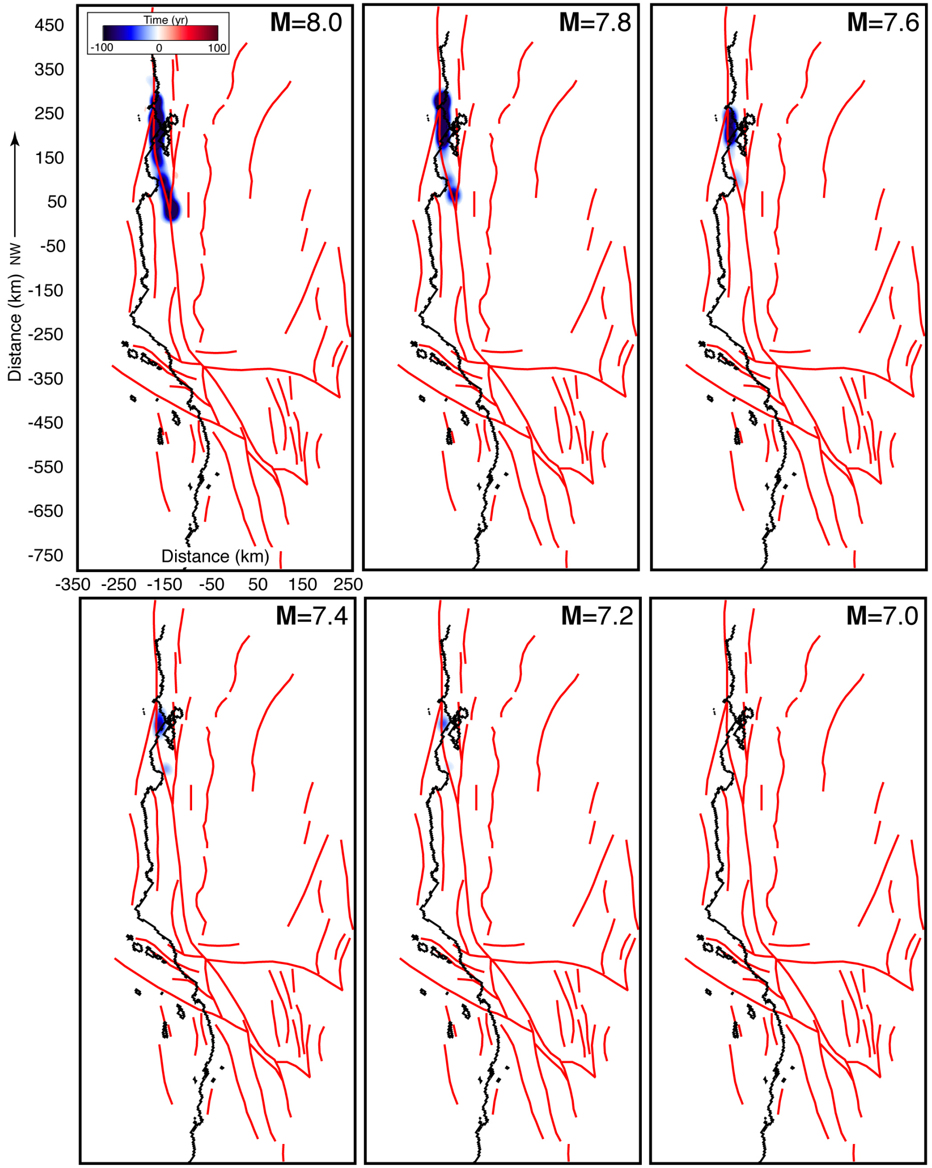


Viscoelastic post-seismic loading is calculated to have variable impact on stress recovery times depending on magnitude and location

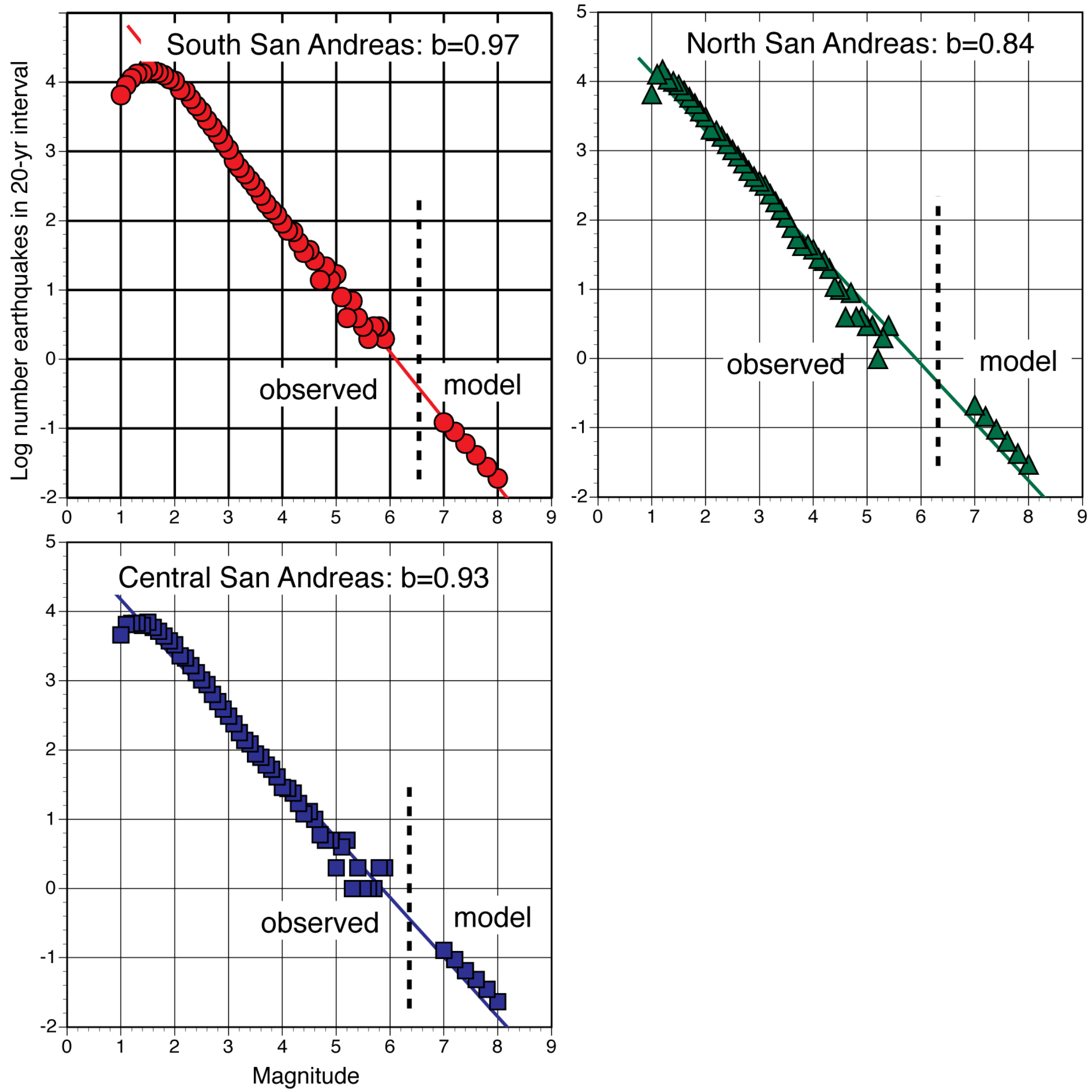
Stress recovery time vs. earthquake magnitude: North San Andreas fault



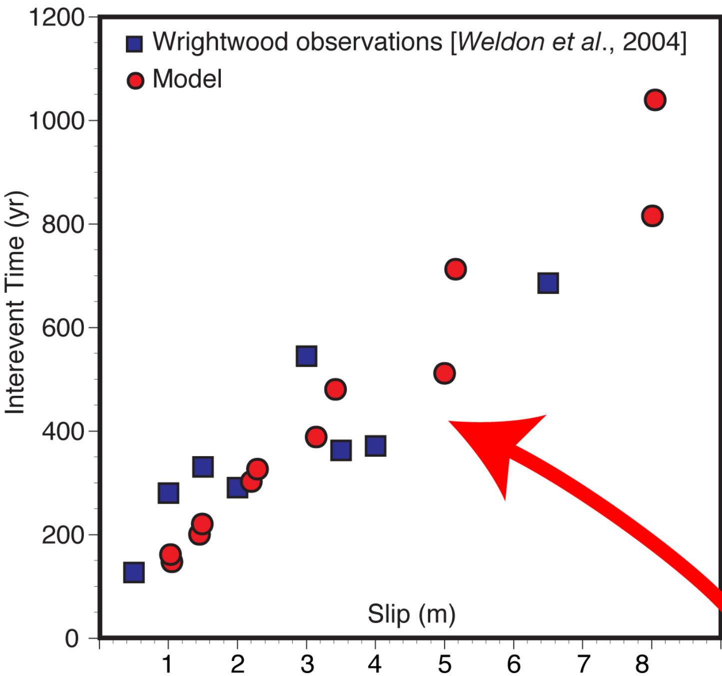
Post-seismic influence on stress recovery vs. earthquake magnitude:
North San Andreas fault



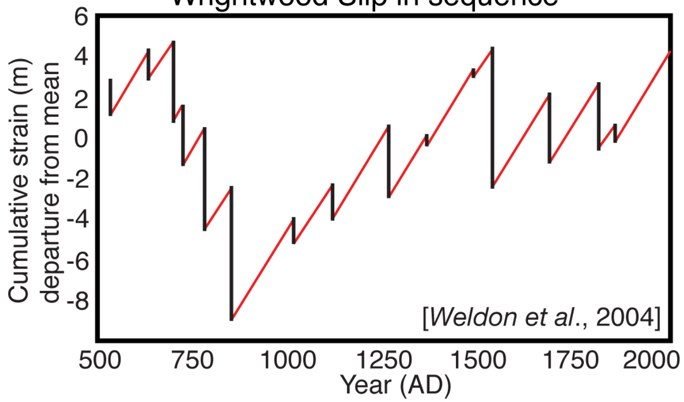
Modeled M≥7.0 San Andreas earthquake rates are consistent with observed M≤7.0 regional magnitude-frequency distributions

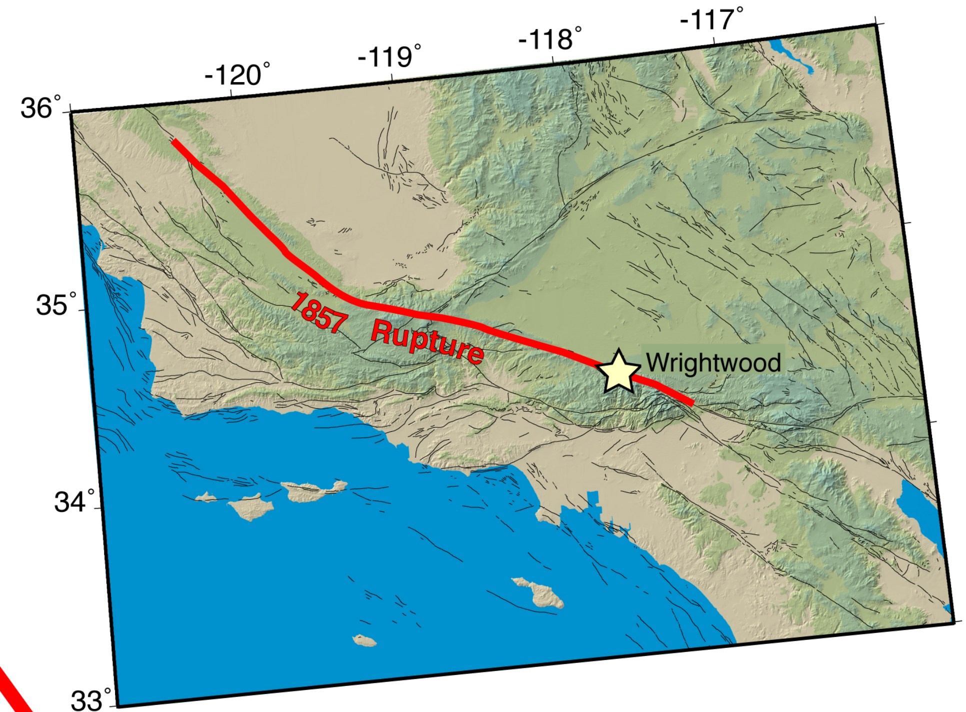


Paleoseismology shows slip variability of San Andreas fault earthquakes in southern California



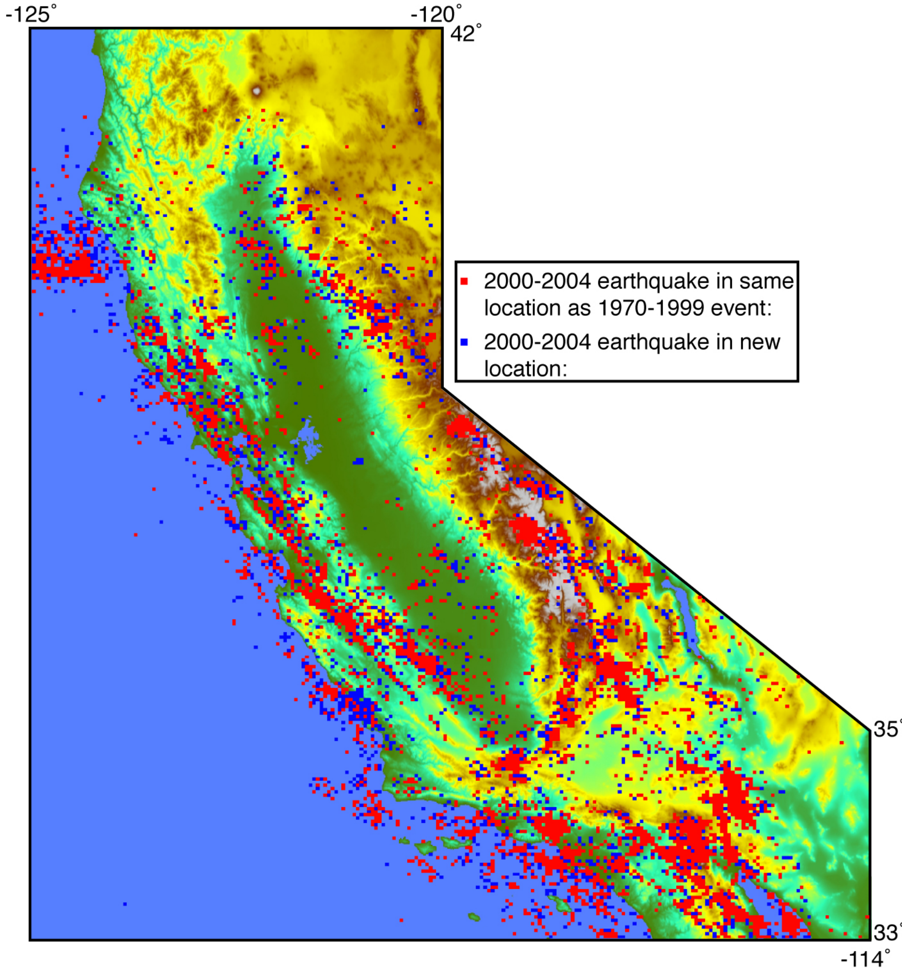
Wrightwood Slip in sequence



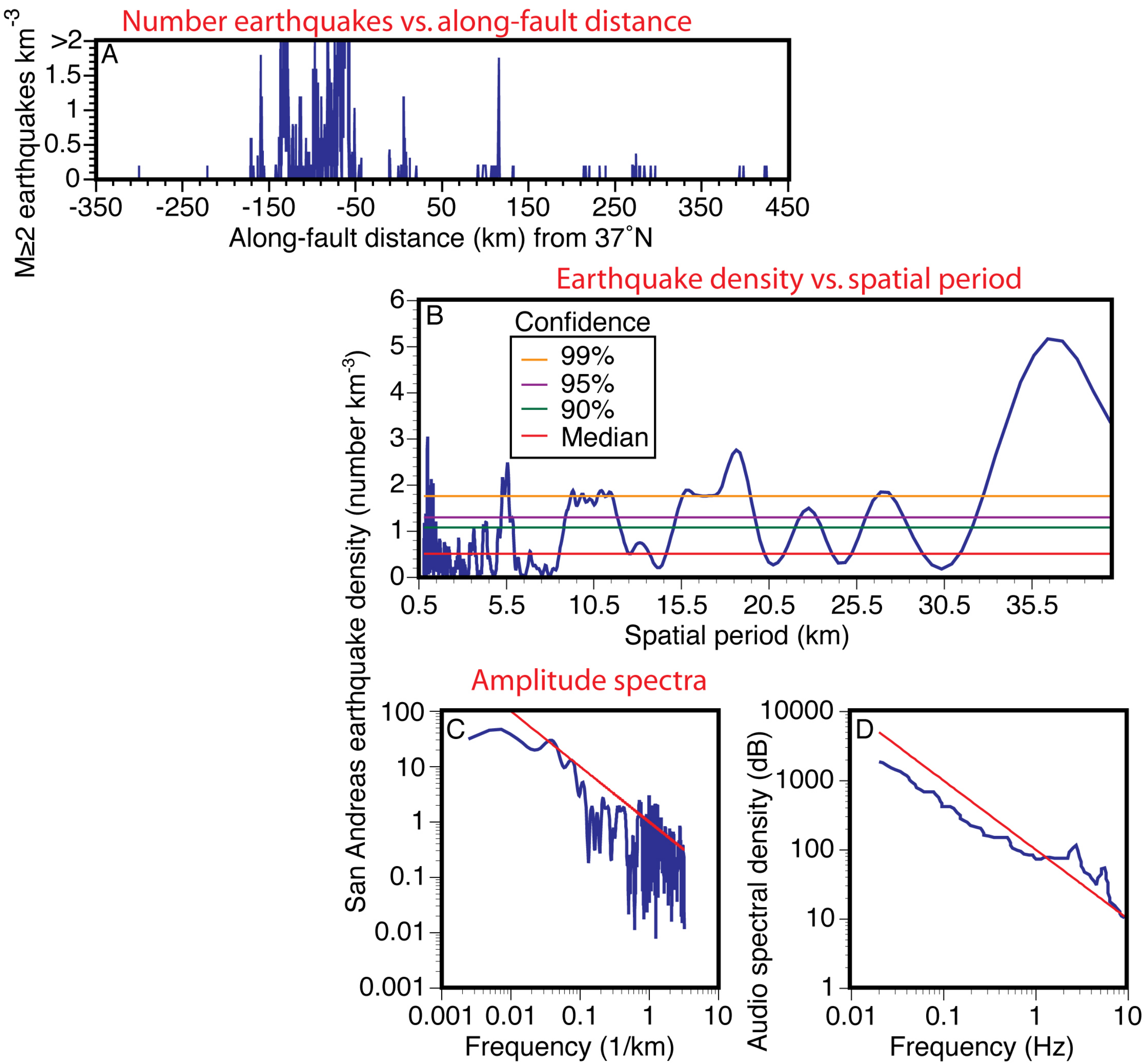


Finite element model with complex loading can reproduce observed slip variability

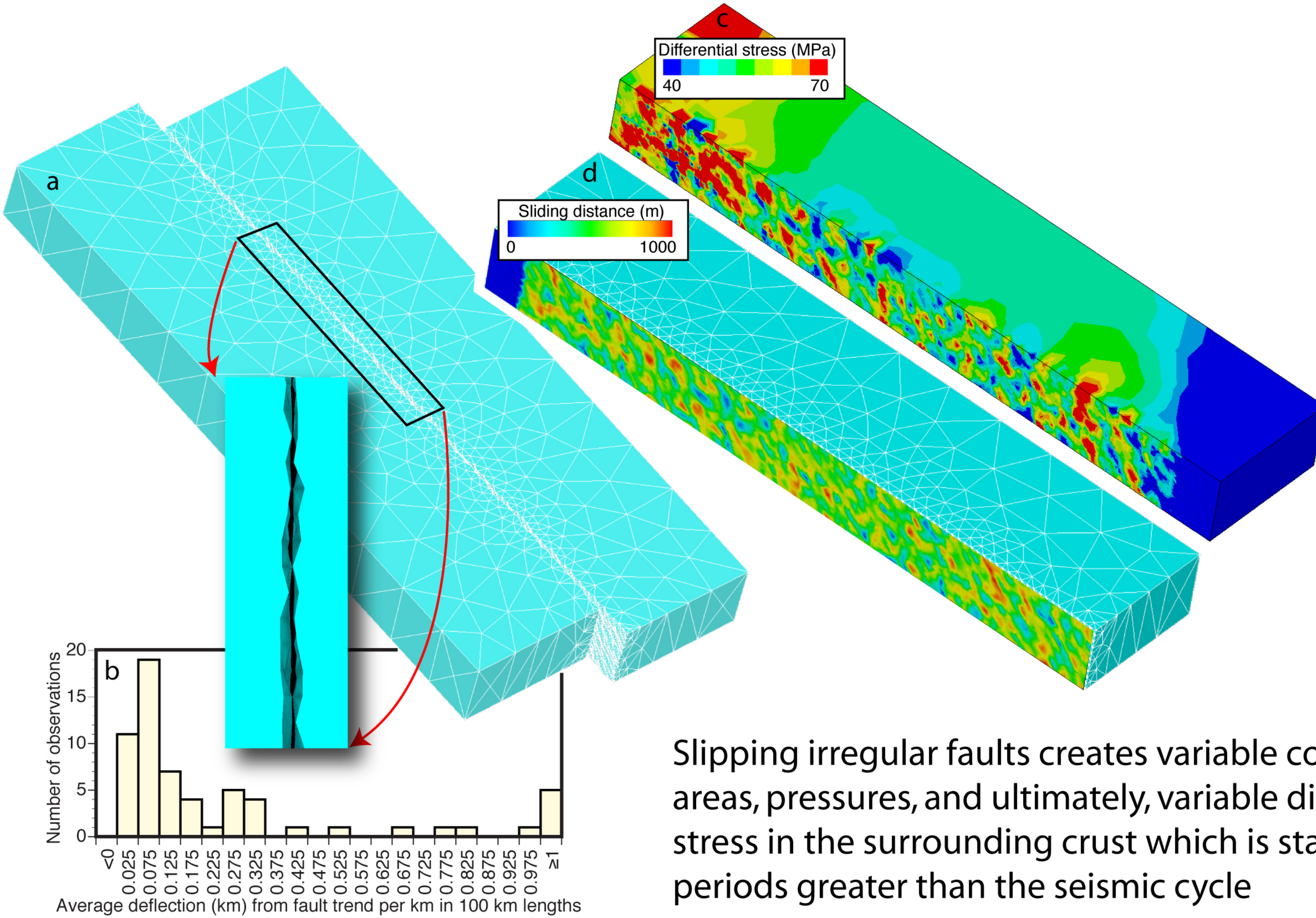
Earthquake cluster and gaps: consequences of long-term stress distribution from slip on irregular faults



San Andreas fault earthquakes are organized by a homogeneous power law distribution



Finite element model with irregular fault structure built from sampling (1-km-scale) mapped San Andreas variations:



Slipping irregular faults creates variable contact areas, pressures, and ultimately, variable differential stress in the surrounding crust which is stable over periods greater than the seismic cycle

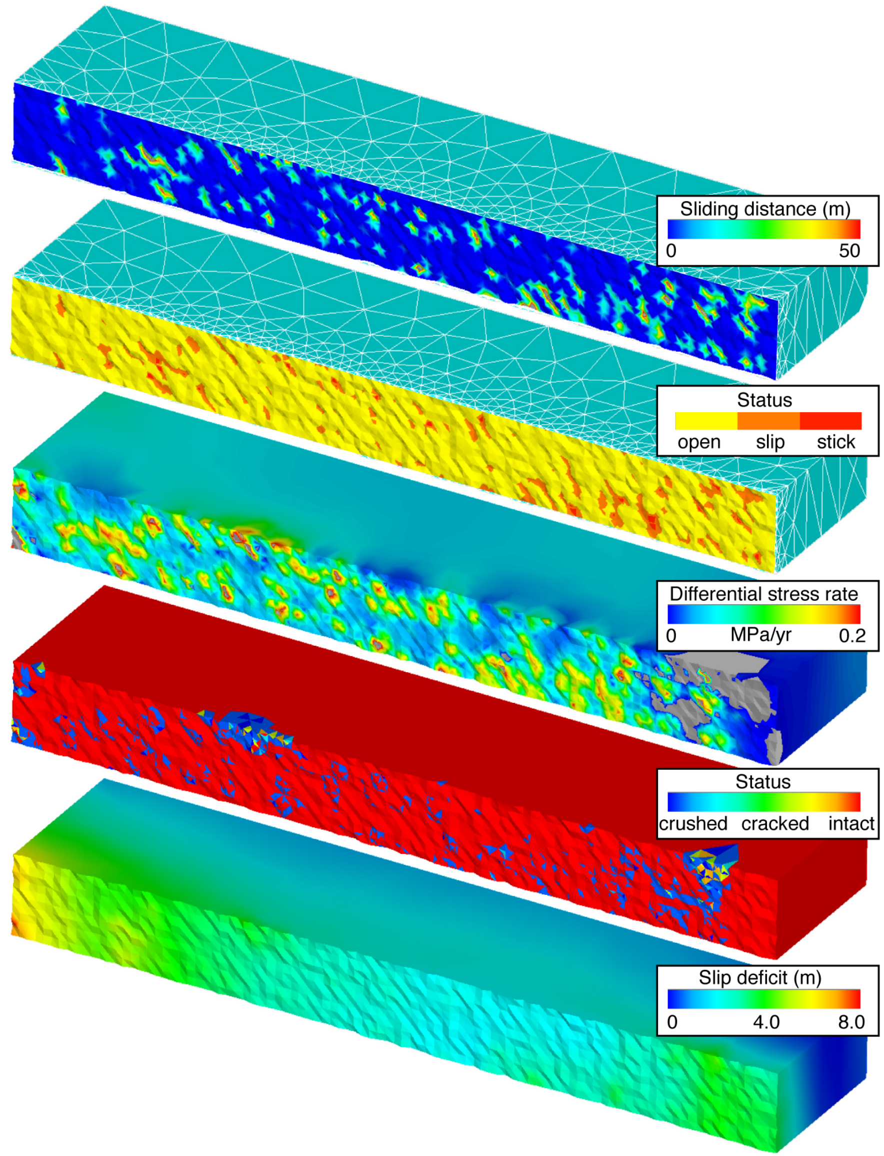
"Rock" elements in ANSYS:

Can crack and crush on planes defined by:

•Principal stresses and pore fluid pressure

•elastic material properties and internal friction coefficient

Element cracking prevents unrealistic stress concentrations



Model with irregular fault contacts generates homogeneous power law distribution of differential stress with the same exponent (-1) as seen in San Andreas earthquake distribution