Jet Propulsion Laboratory
California Institute of Technology

InSAR observations of tectonic deformation on active faults in California

Ekaterina Tymofyeyeva*

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*Jet Propulsion Laboratory, California Institute of Technology

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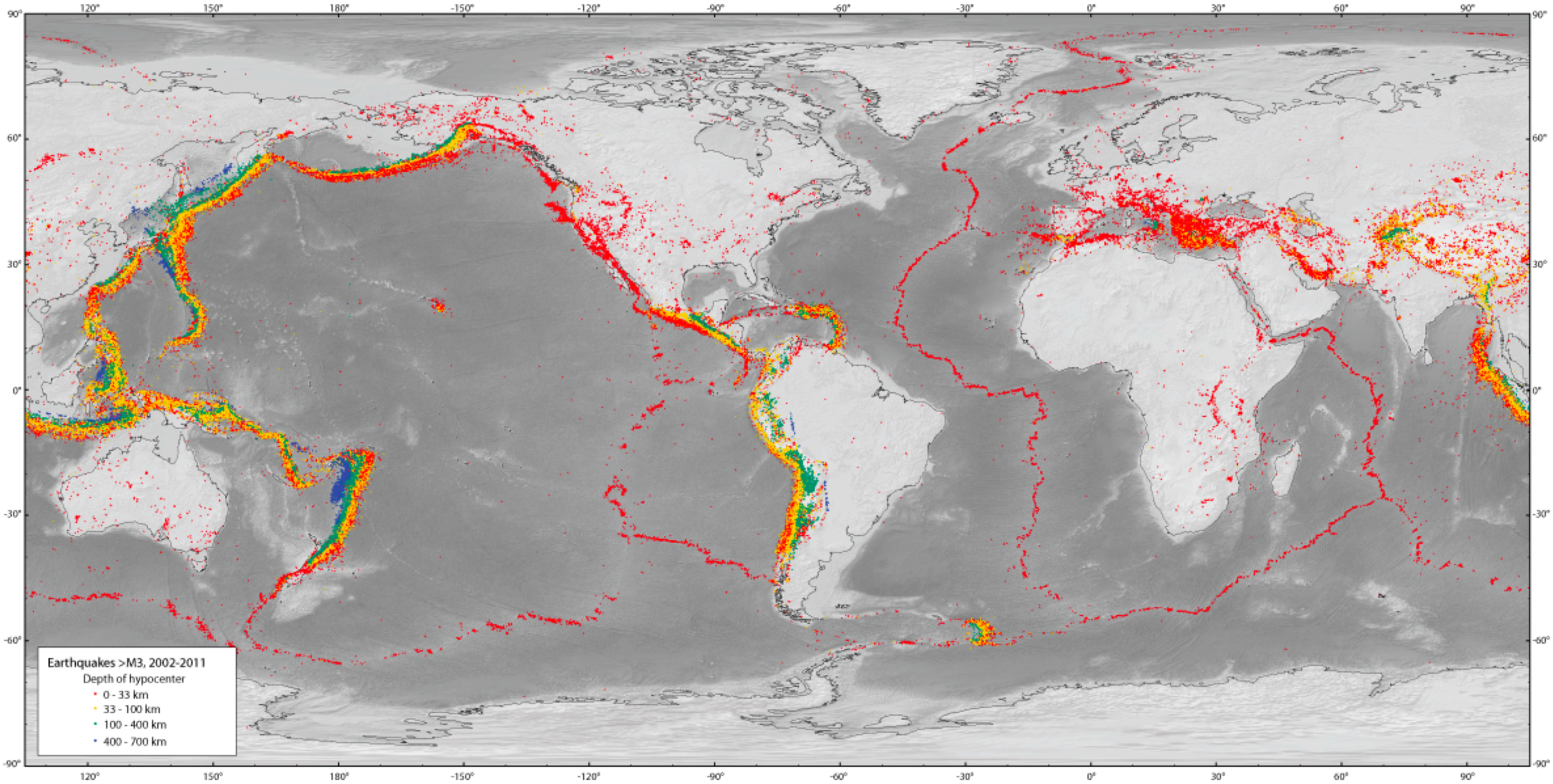
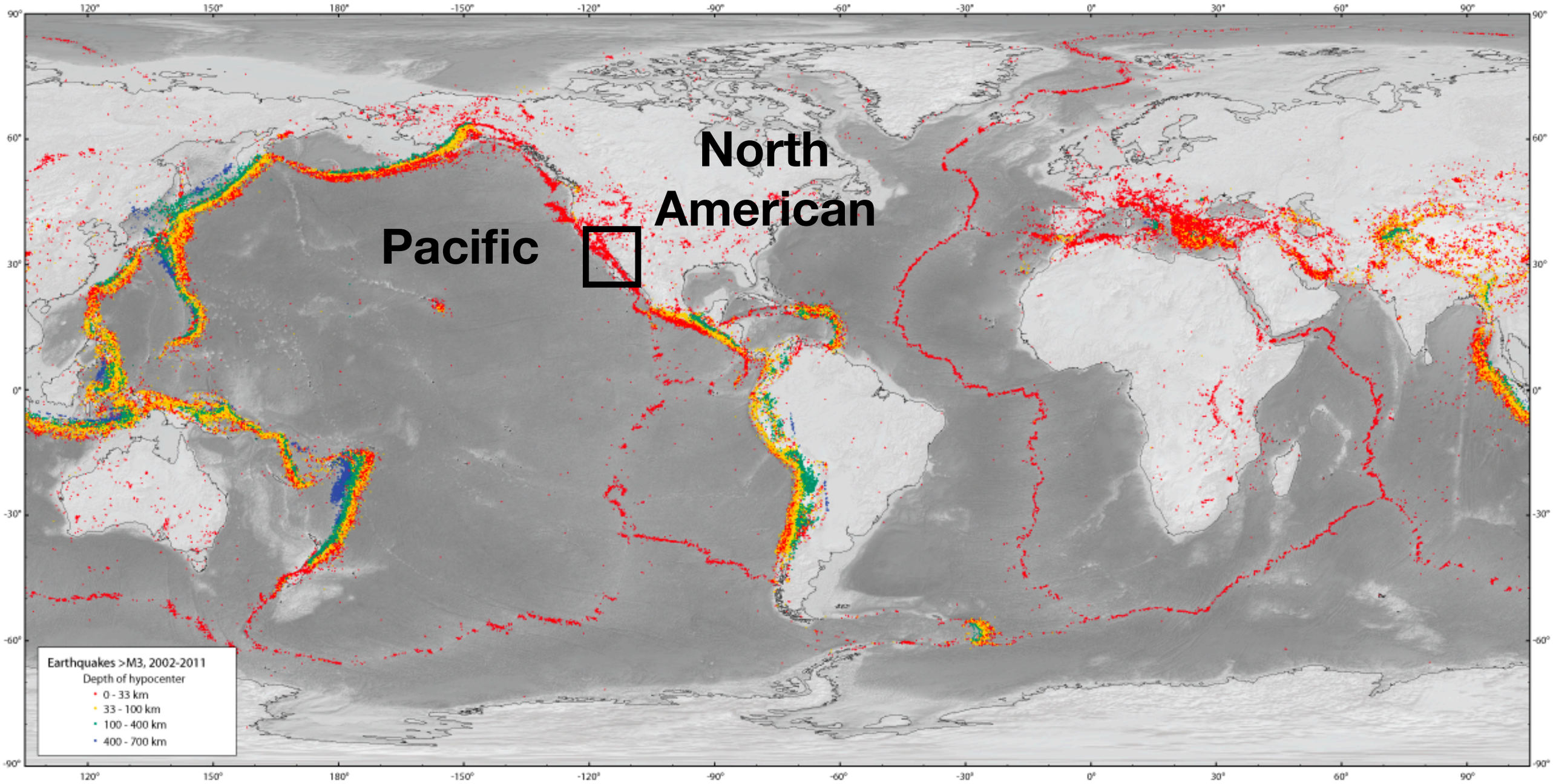
Global distribution of earthquakes (> Mw. 3)



(http://science.sciencemag.org/)

Global distribution of earthquakes (> Mw. 3)



(http://science.sciencemag.org/)

CALIFORNIA

North
American
Pacific
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
Image Landsat / Copernicus
323 km
Imagery Date: 12/13/2015 lat 37.298726° lon -118.989330° elev 3

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Canada
Juan de Fuca
Plate →
NORTH AMERICAN
PLATE
United States
San Andreas Fault
PACIFIC PLATE
Mexico

CALIFORNIA

North
American
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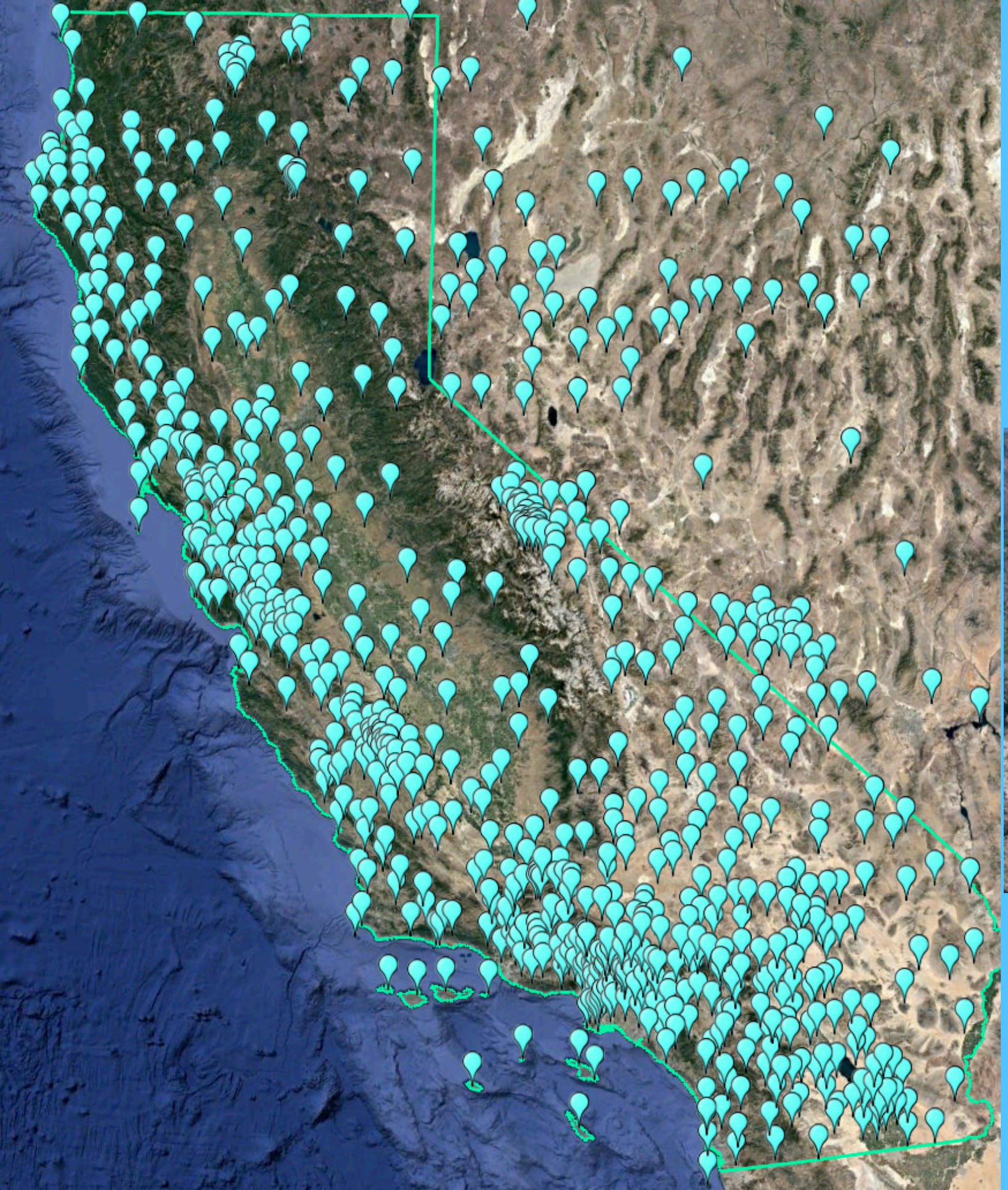
Data LDEO-Columbia, NSF, NOAA
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
lat 37.667742° lon -114.628283°

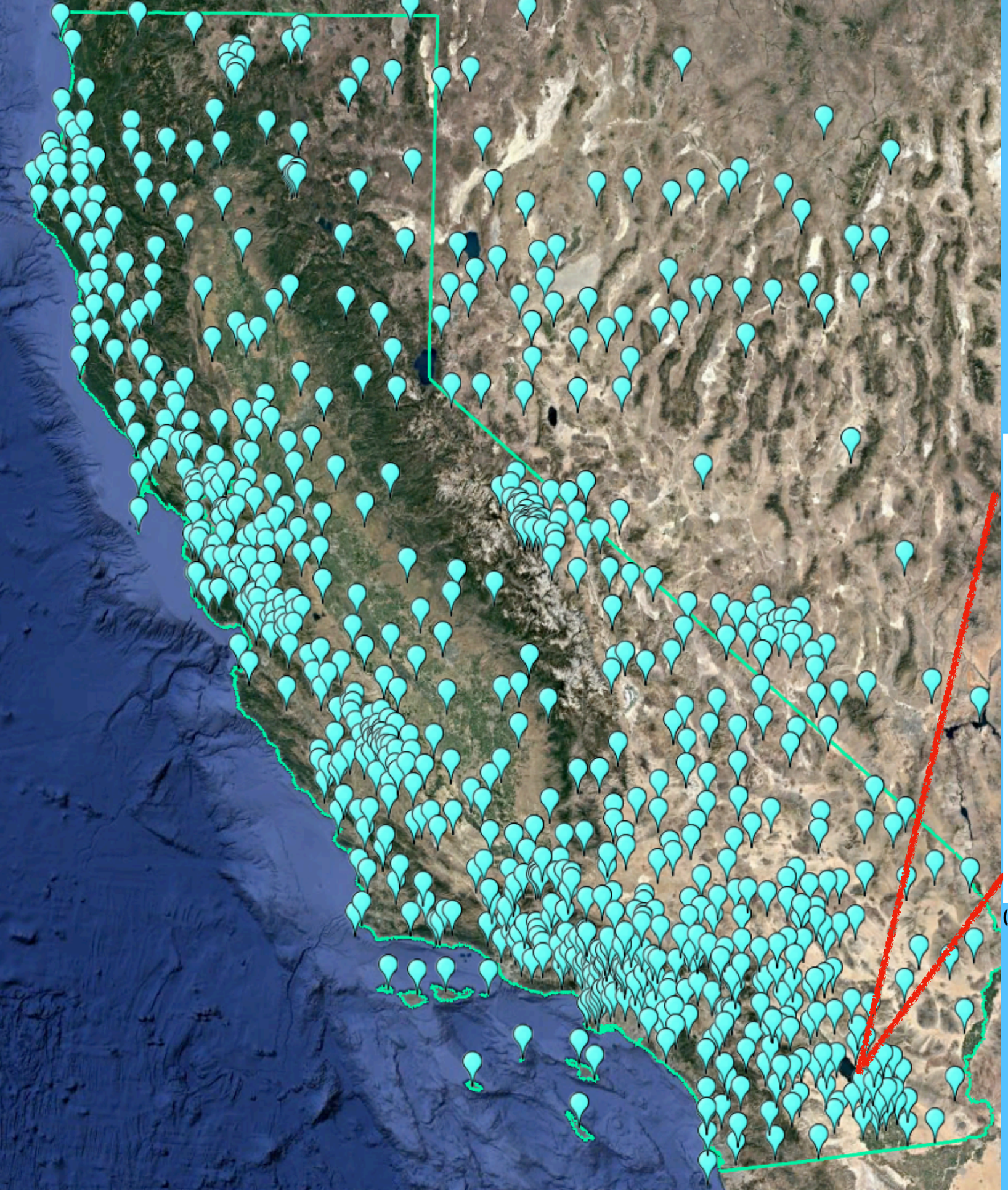
Canada
Juan de Fuca
Plate →
NORTH AMERICAN
PLATE
United States
San Andreas Fault
PACIFIC PLATE
Mexico

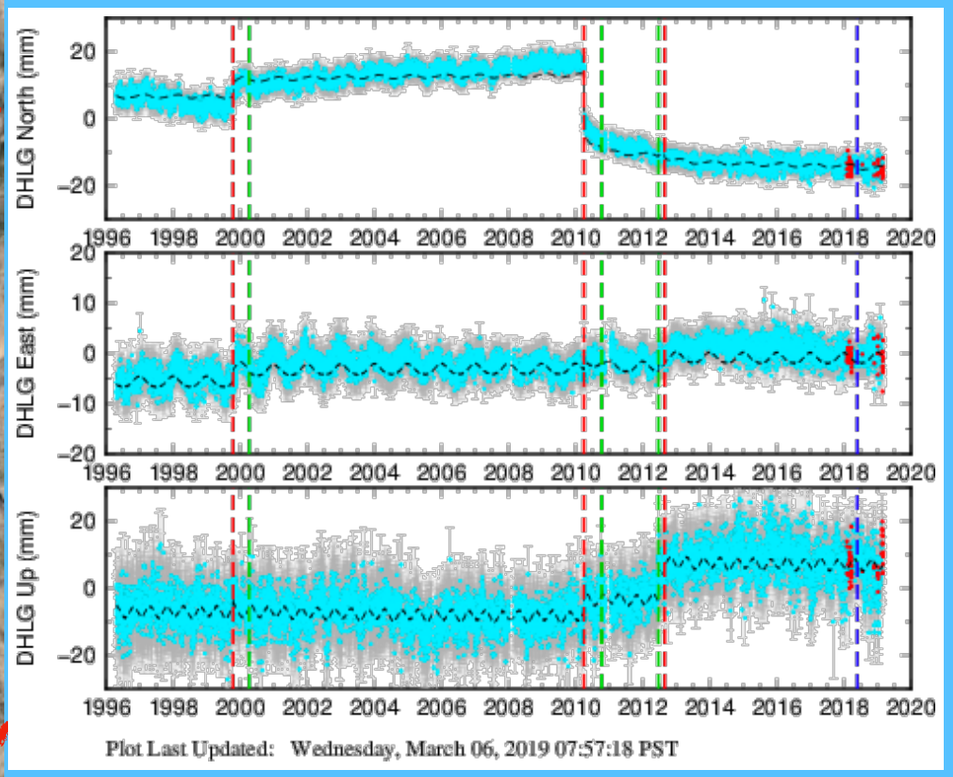


CONTINUOUSLY RECORDING GPS INSTRUMENTS

(tectonics.caltech.edu)

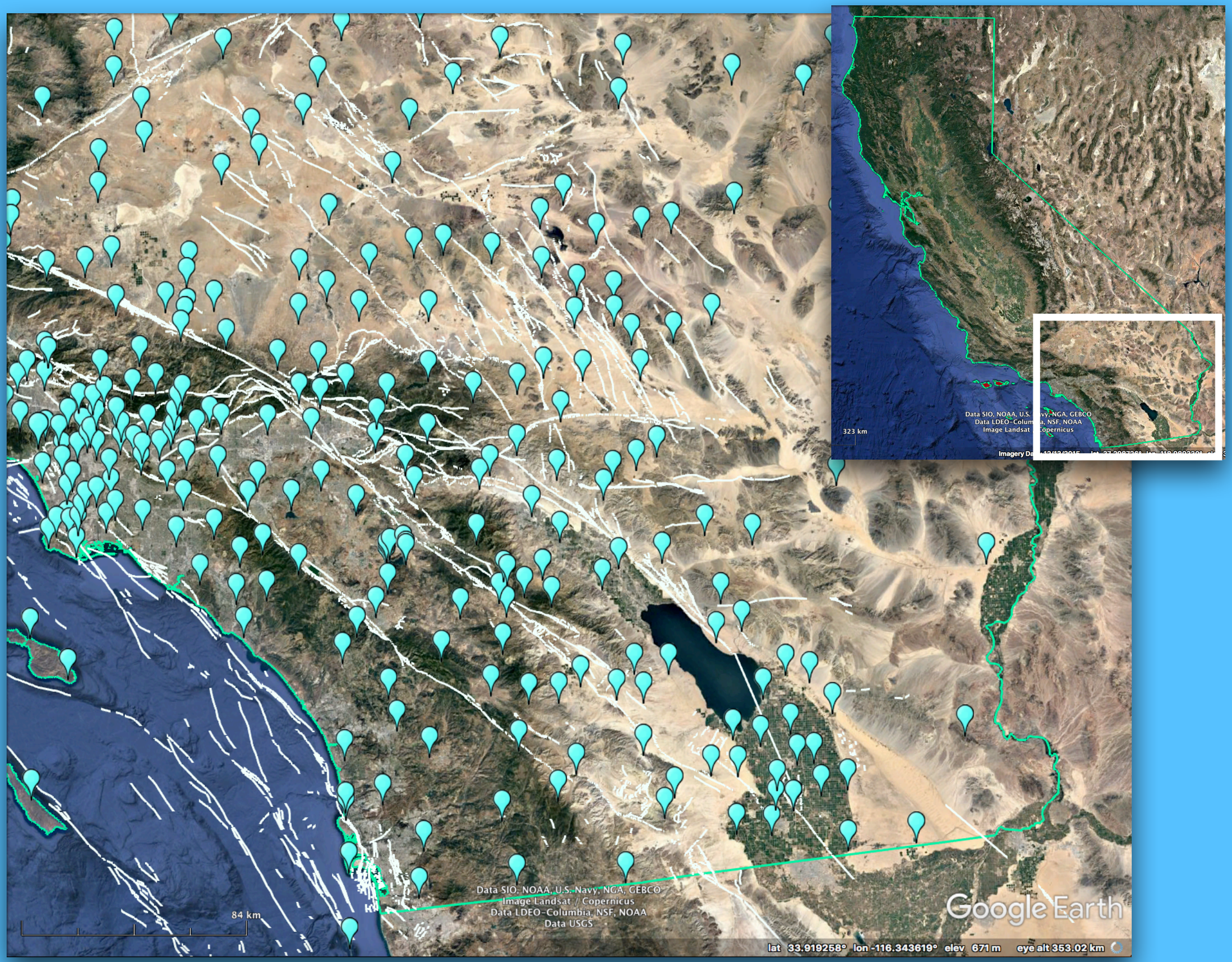
CONTINUOUSLY RECORDING GPS INSTRUMENTS





(https://earthquake.usgs.gov/monitoring/gps/Southern_California/dhlg)

CONTINUOUSLY RECORDING GPS INSTRUMENTS



Interferometric Synthetic Aperture Radar

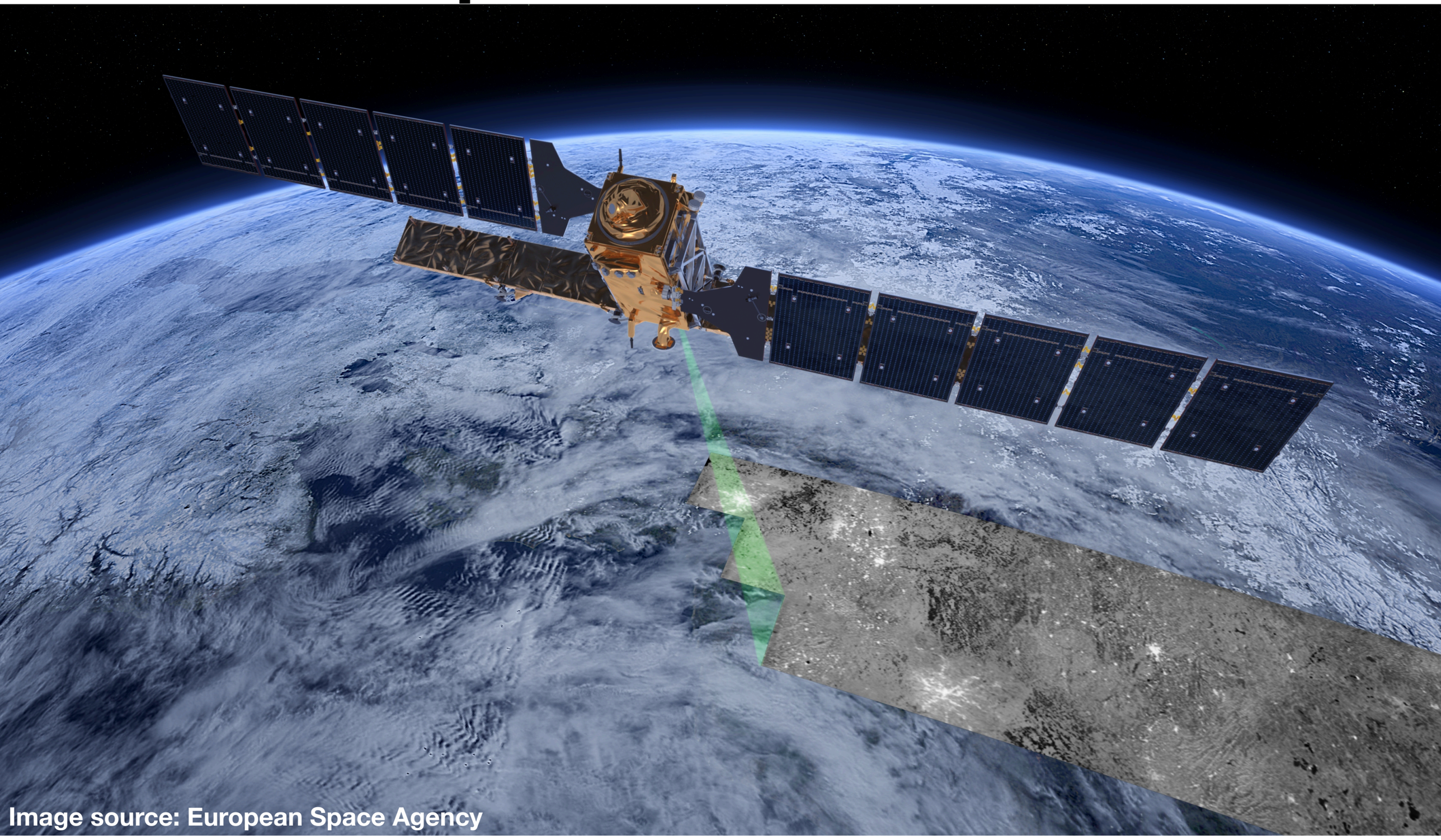


Image source: European Space Agency

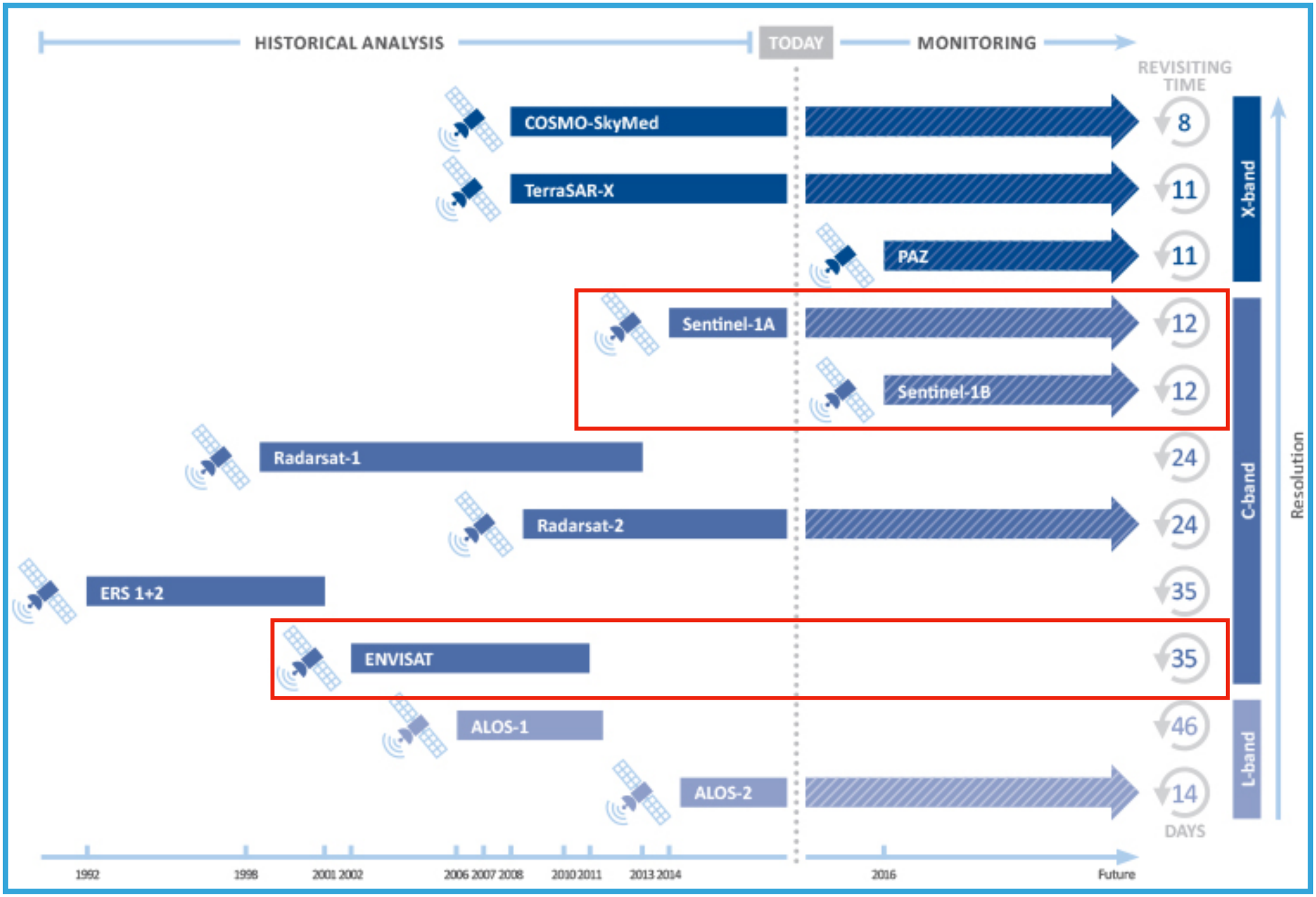
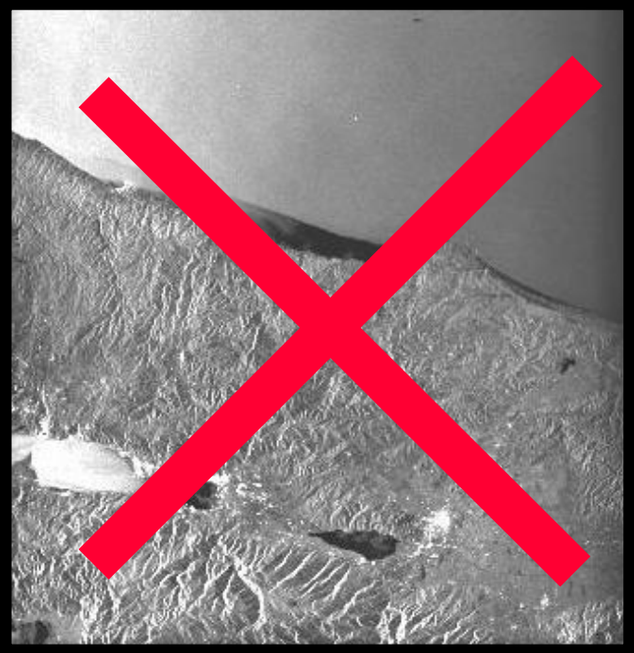
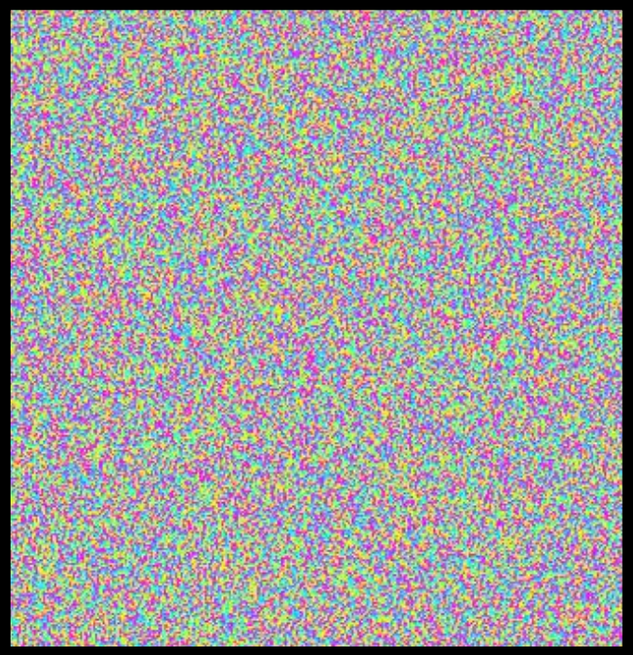
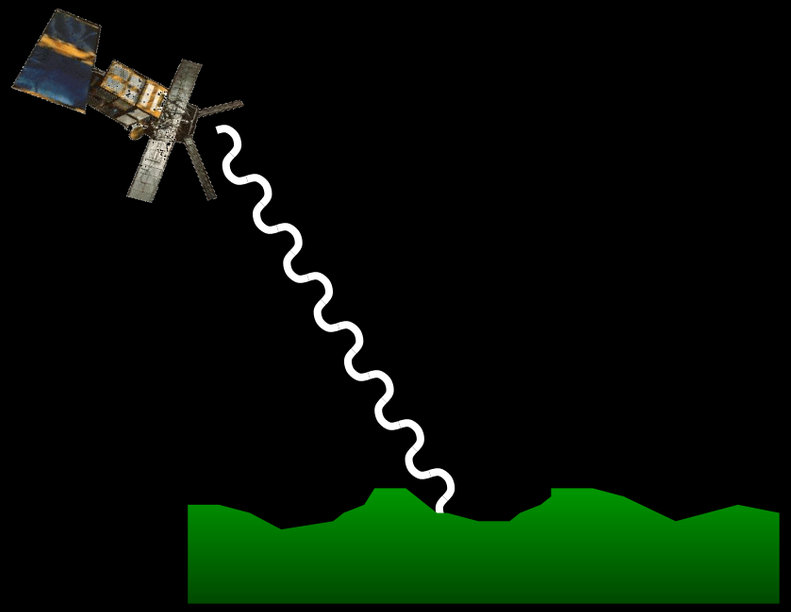


Image source: European Space Agency

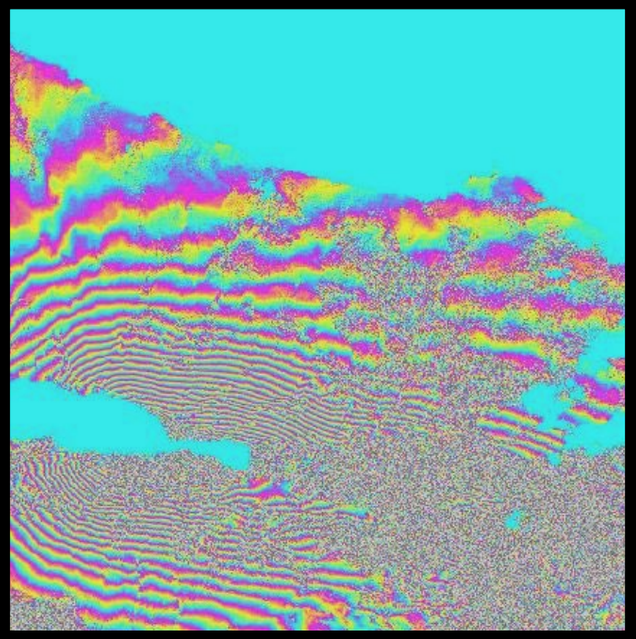
Image A - 12 August 1999

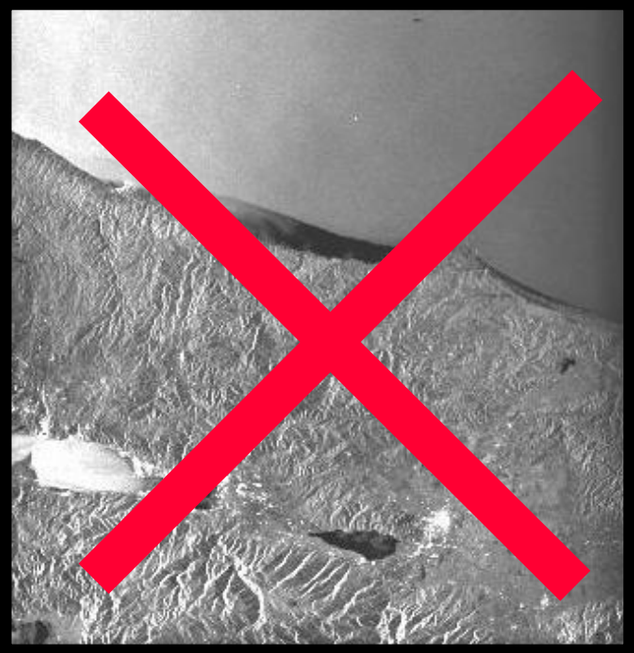


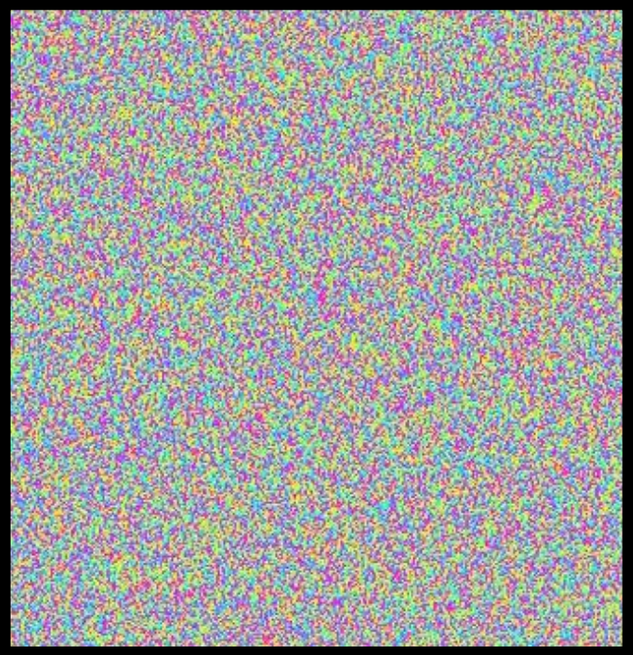




InSAR image







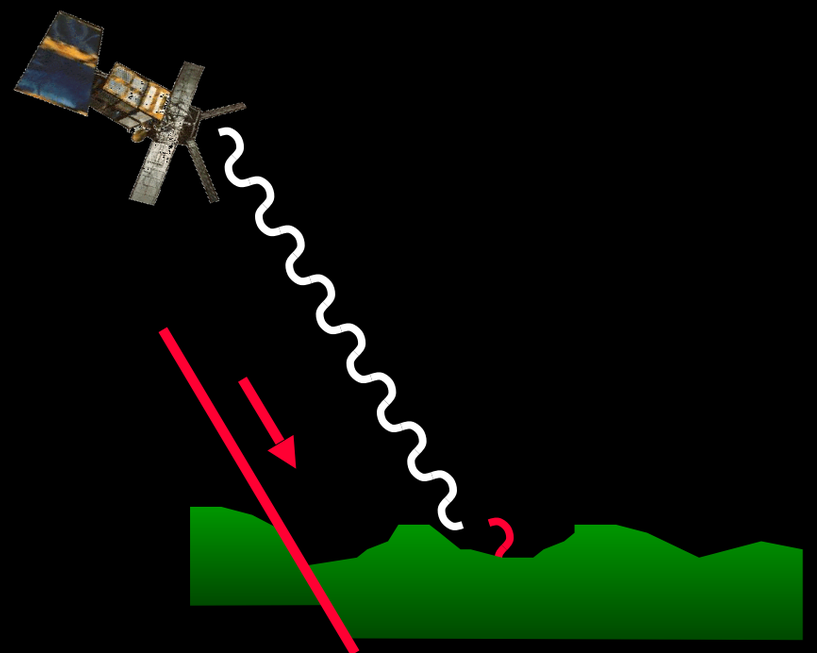


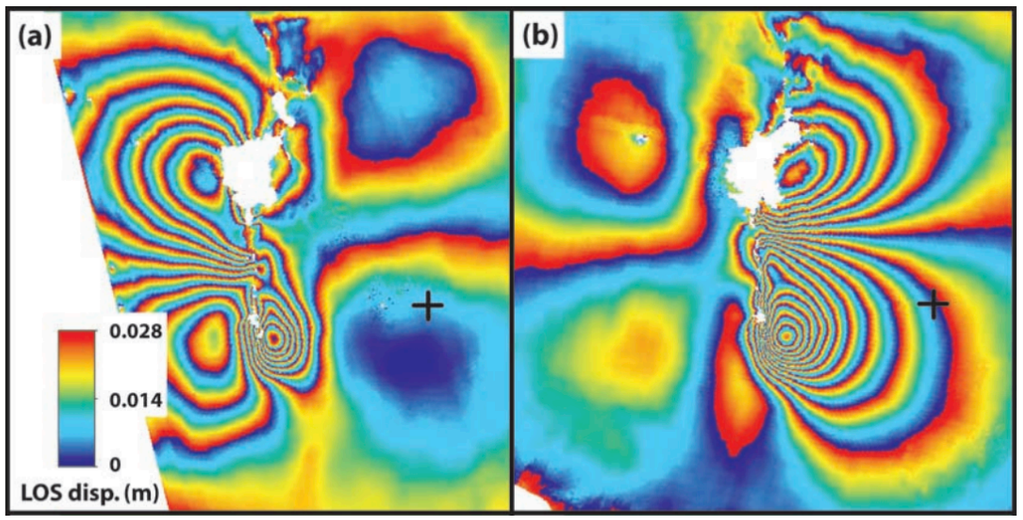
Image B - 16 September 1999

Massonnet, D., M. Rossi, C. Carmona, F. Adragna, G. Peltzer, K. Feigl, and T. Rabaute, The displacement field of the Landers earthquake mapped by radar interferometry, Nature, 364, 138-142, 1993.

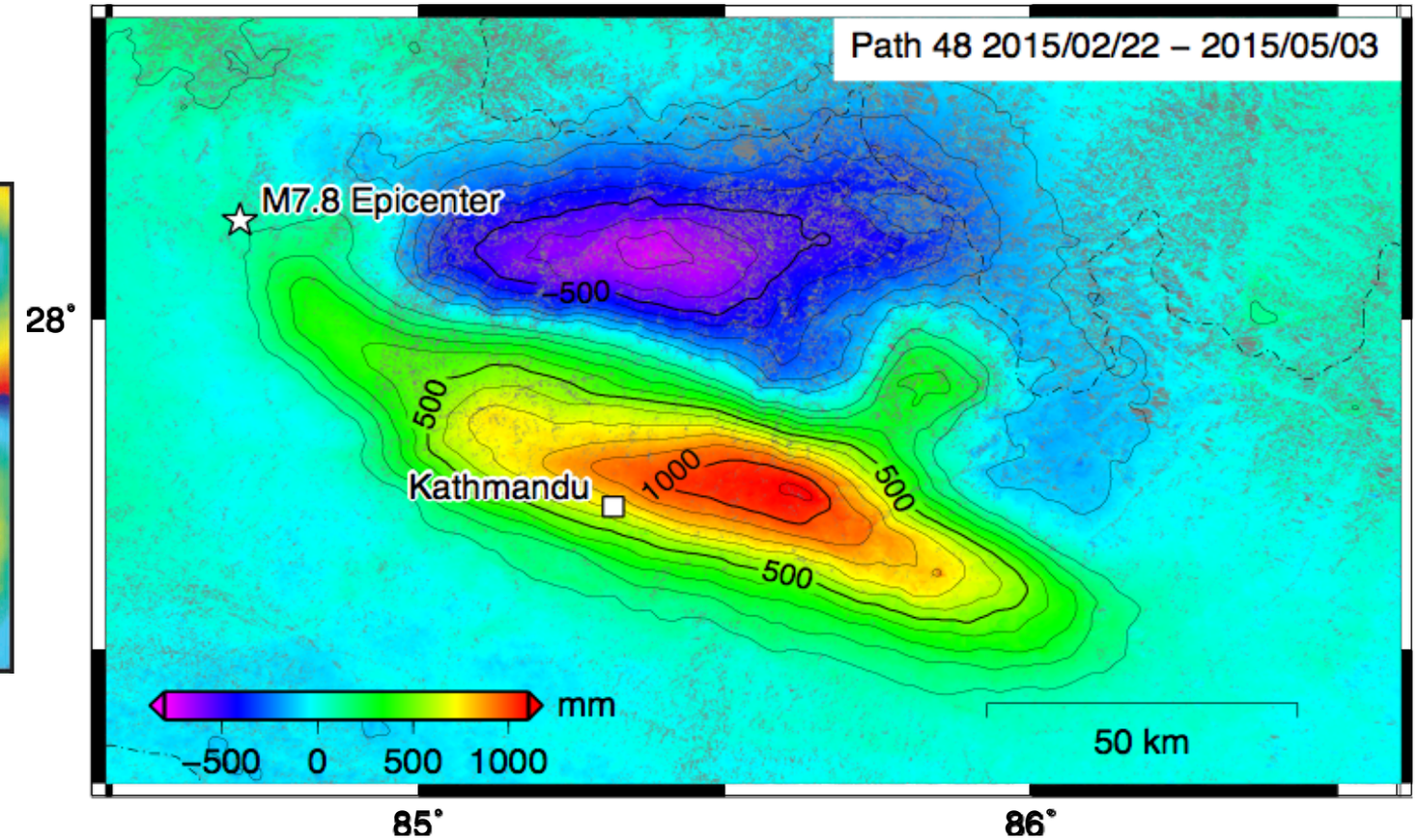
Mw 7.3 Landers earthquake, 1992

Bam, Iran earthquake, 2003

Funning et al., 2005



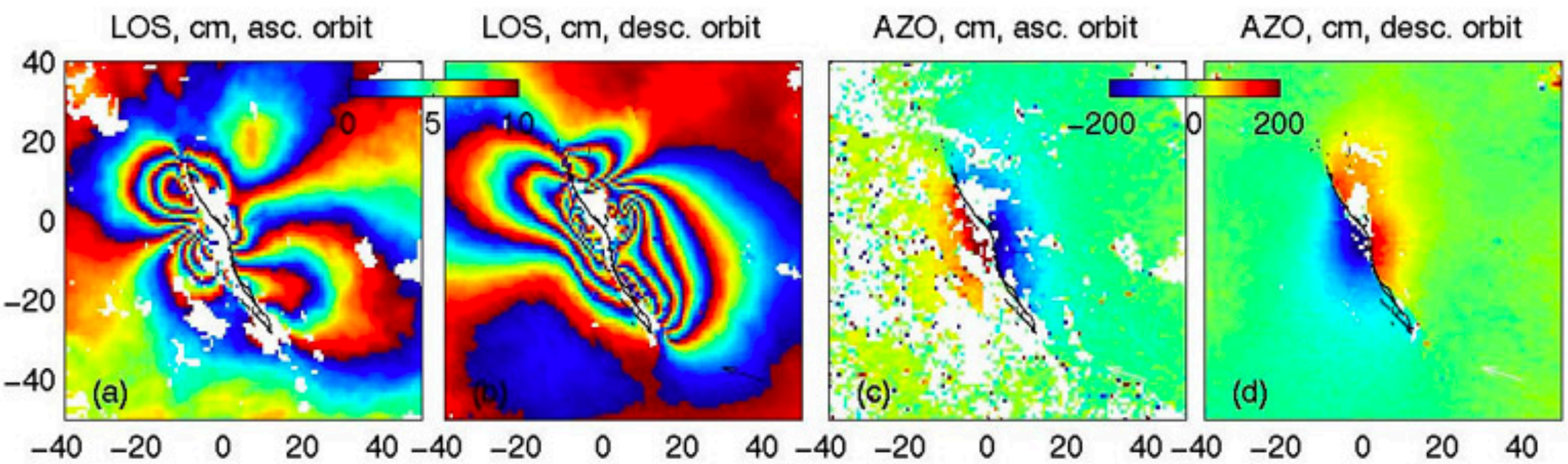
Gorkha earthquake, 2015

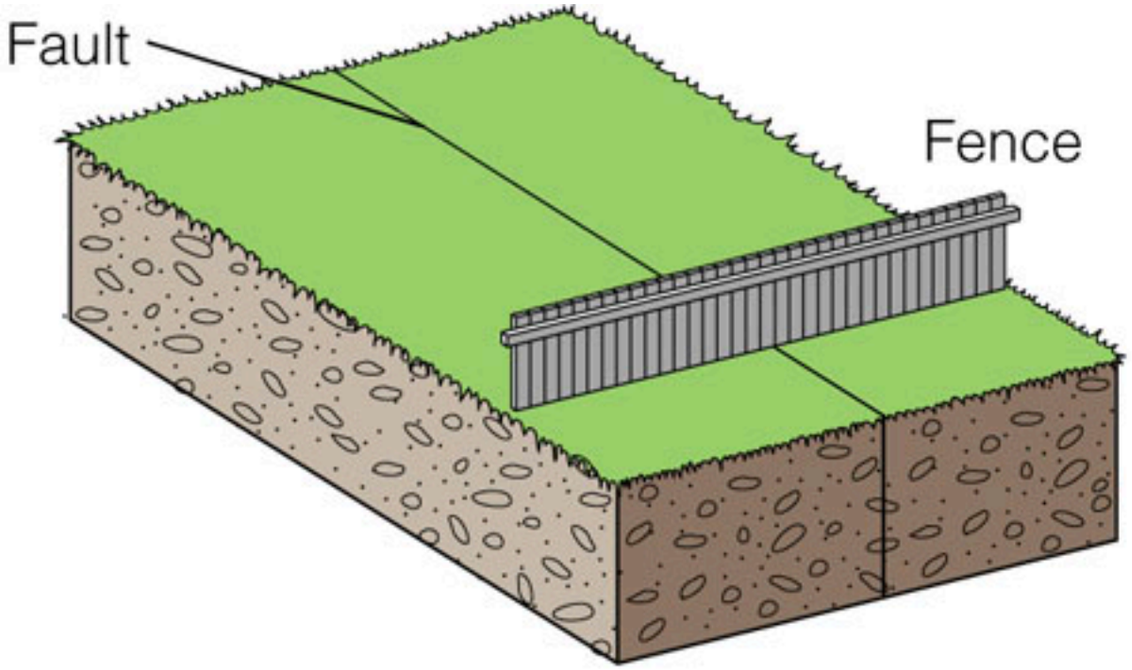


Lindsey et al., 2015

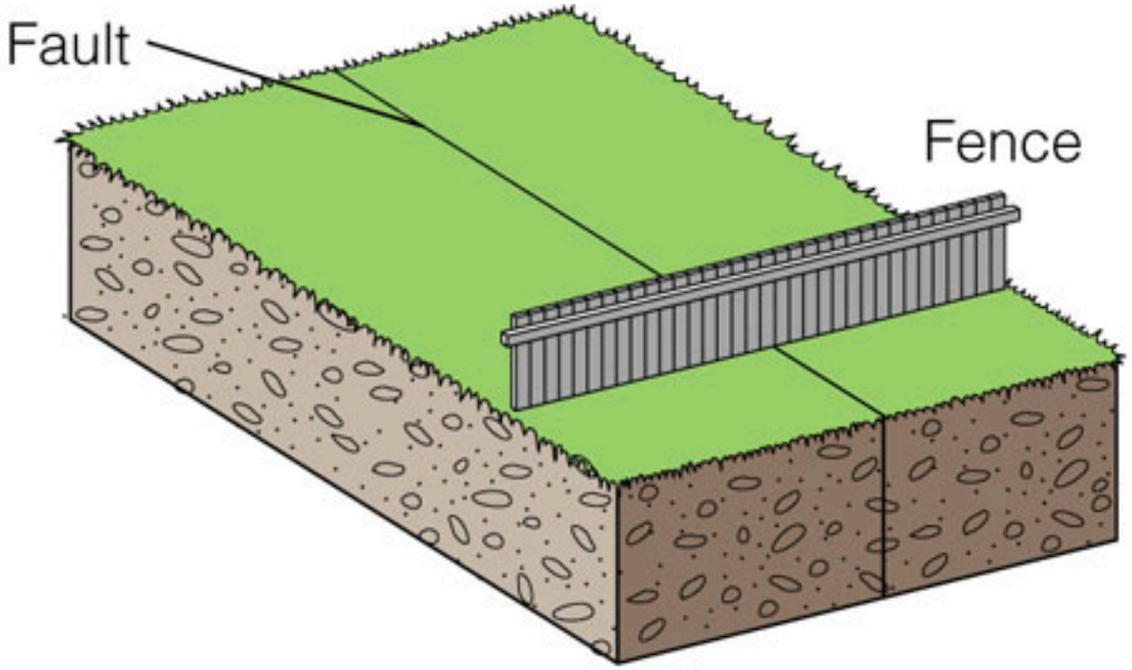
Hector Mine earthquake, 1999

Fialko et al., 2001





(a) Original position



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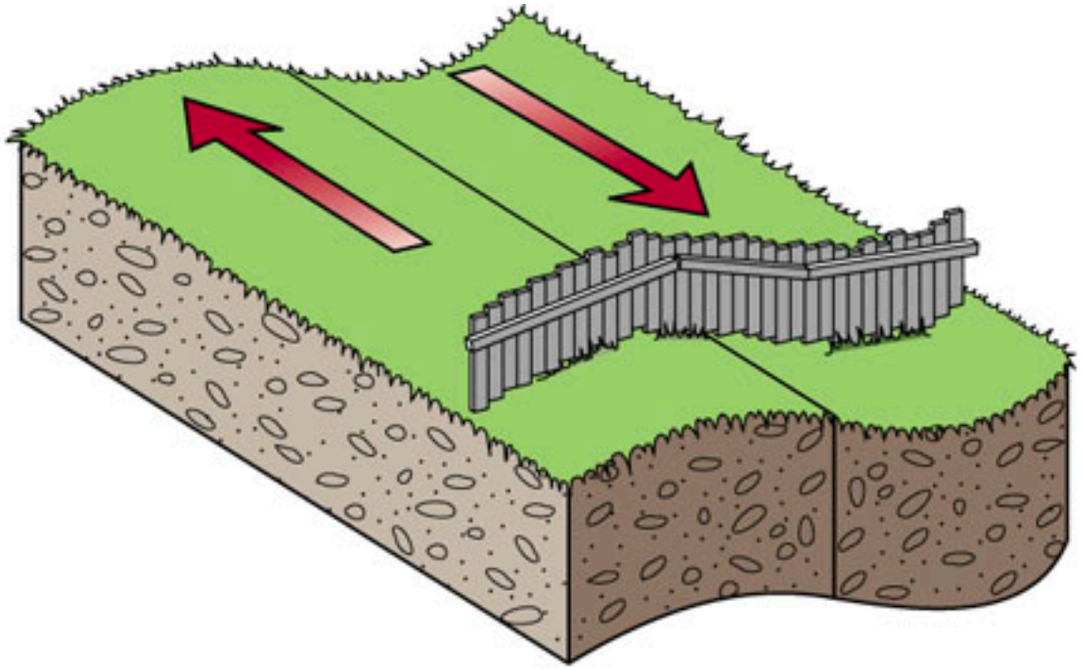
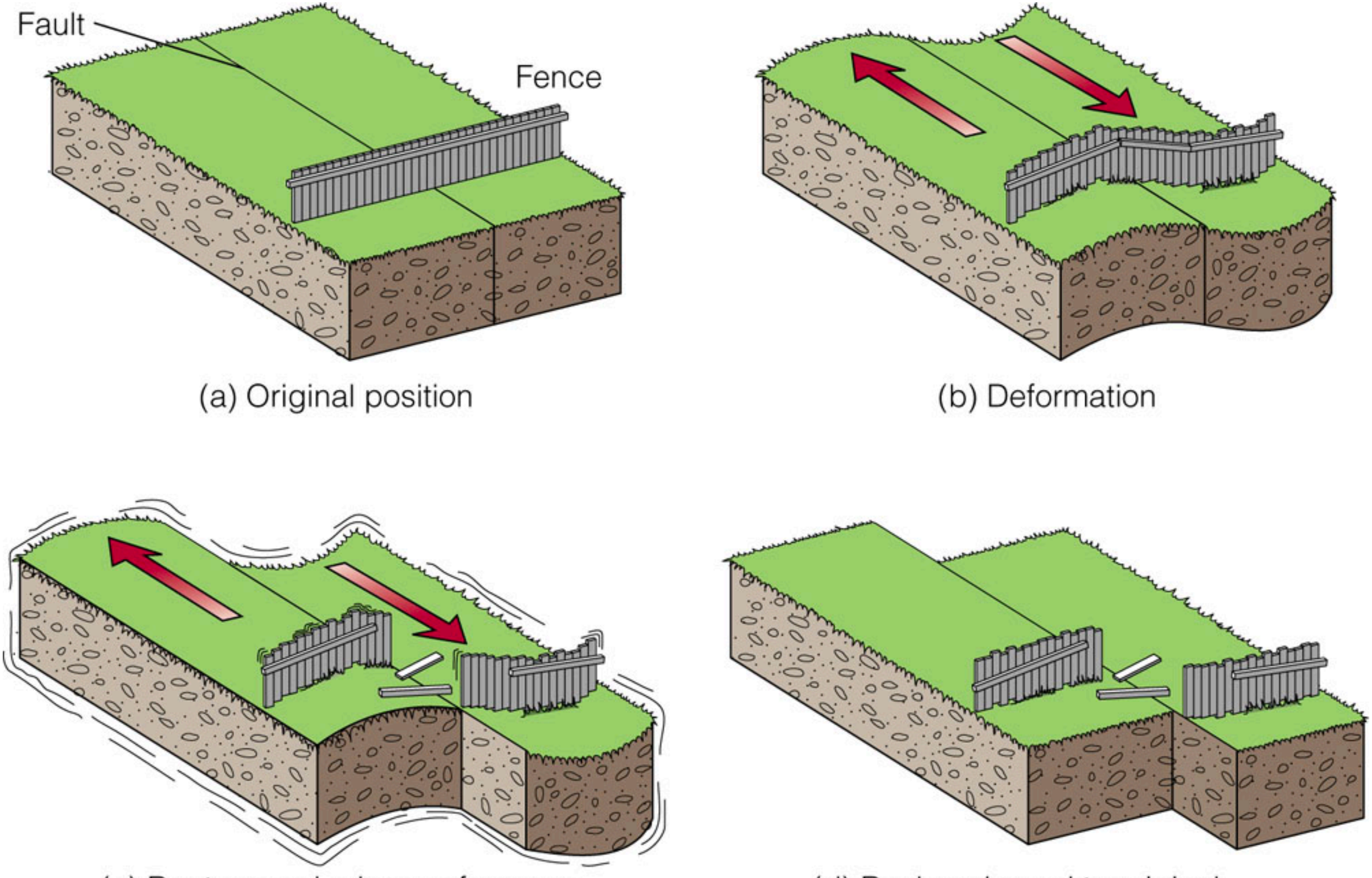


(b) Deformation



(a) Original position

(b) Deformation

(c) Rupture and release of energy

(d) Rocks rebound to original undeformed shape

© 2006 Brooks/Cole - Thomson

Earthquake Cycle

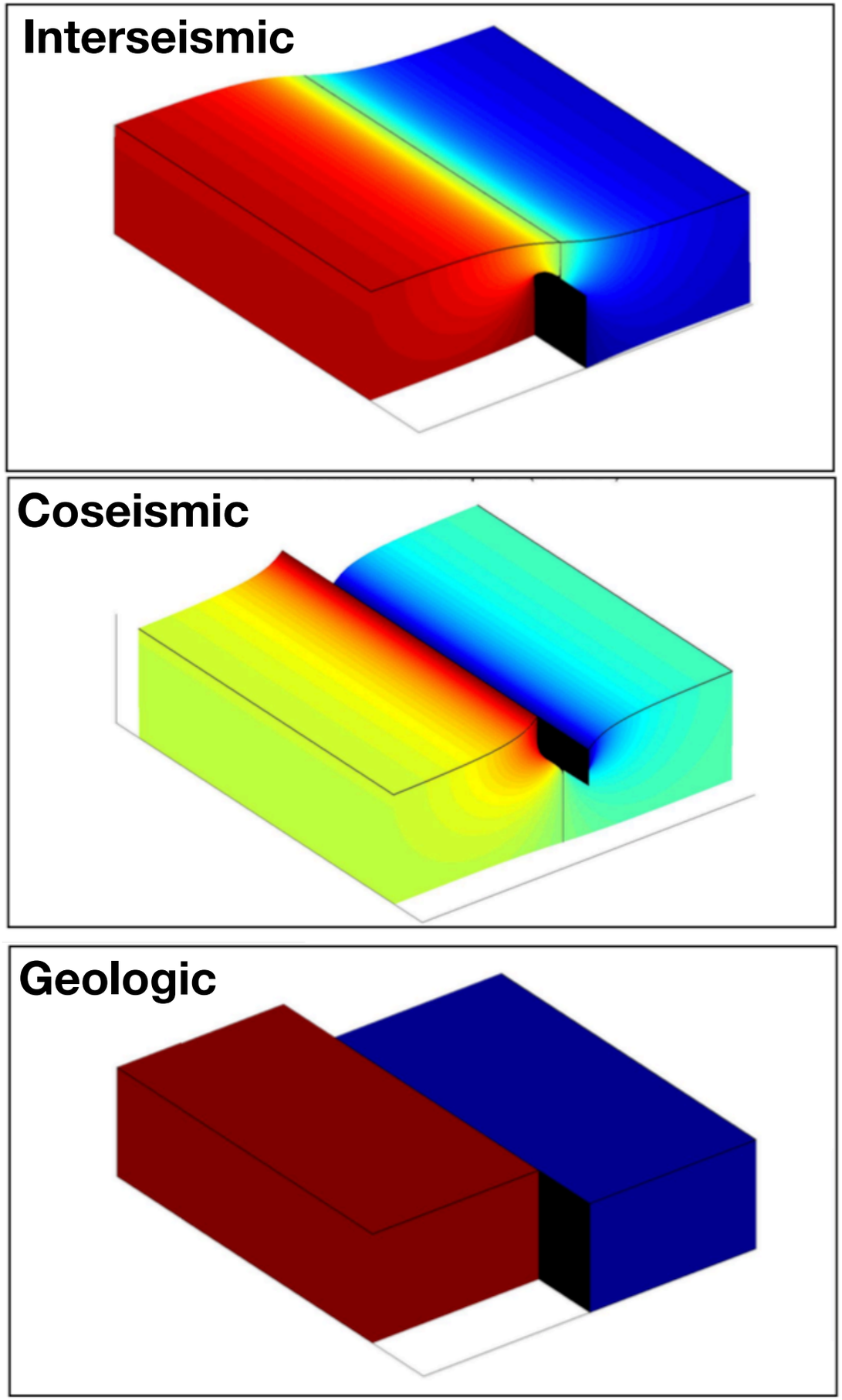
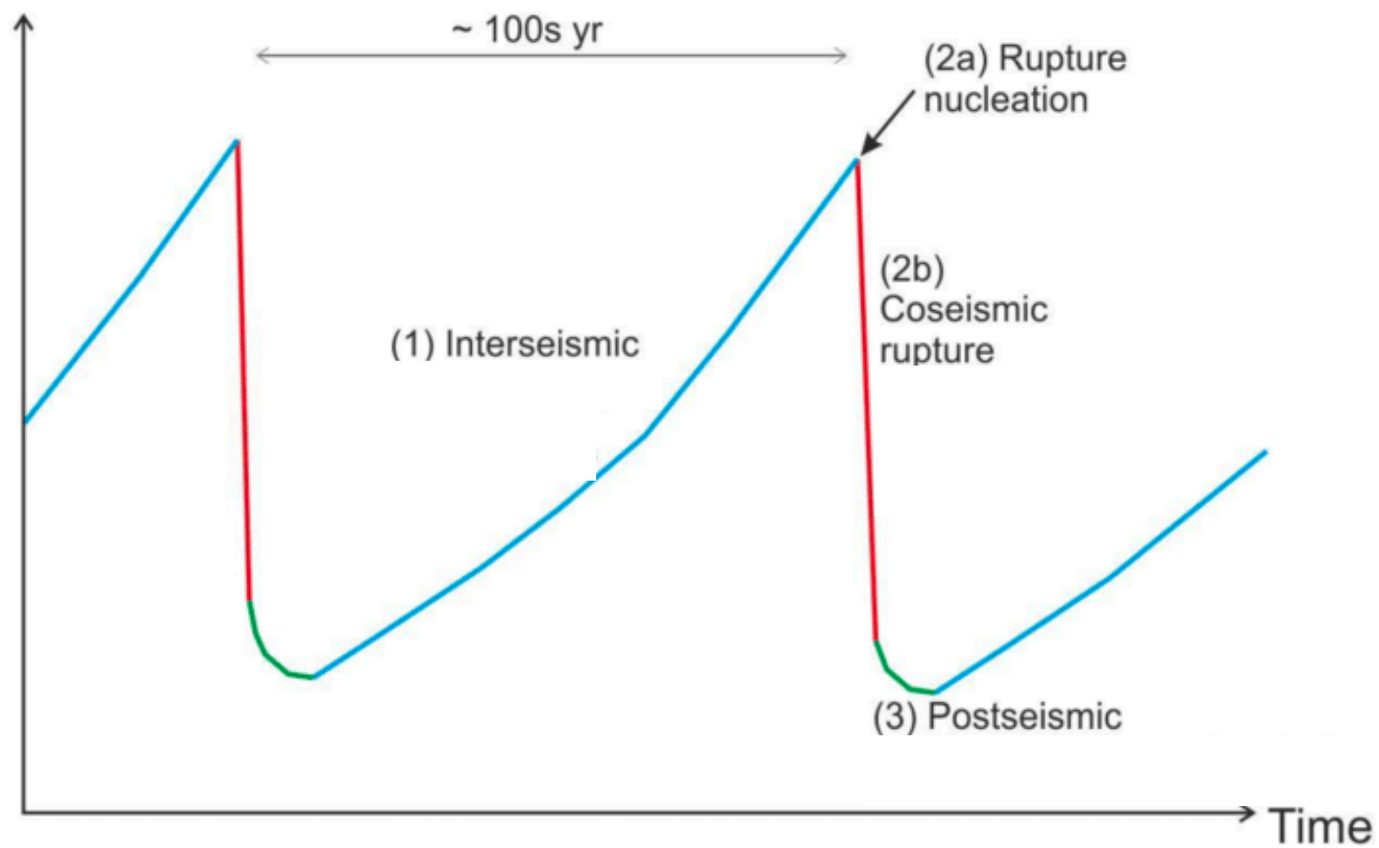


Image source: Yuri Fialko



Hicks, 2015

USGS
science for a changing world

SCEC
AN NSF+USGS CENTER

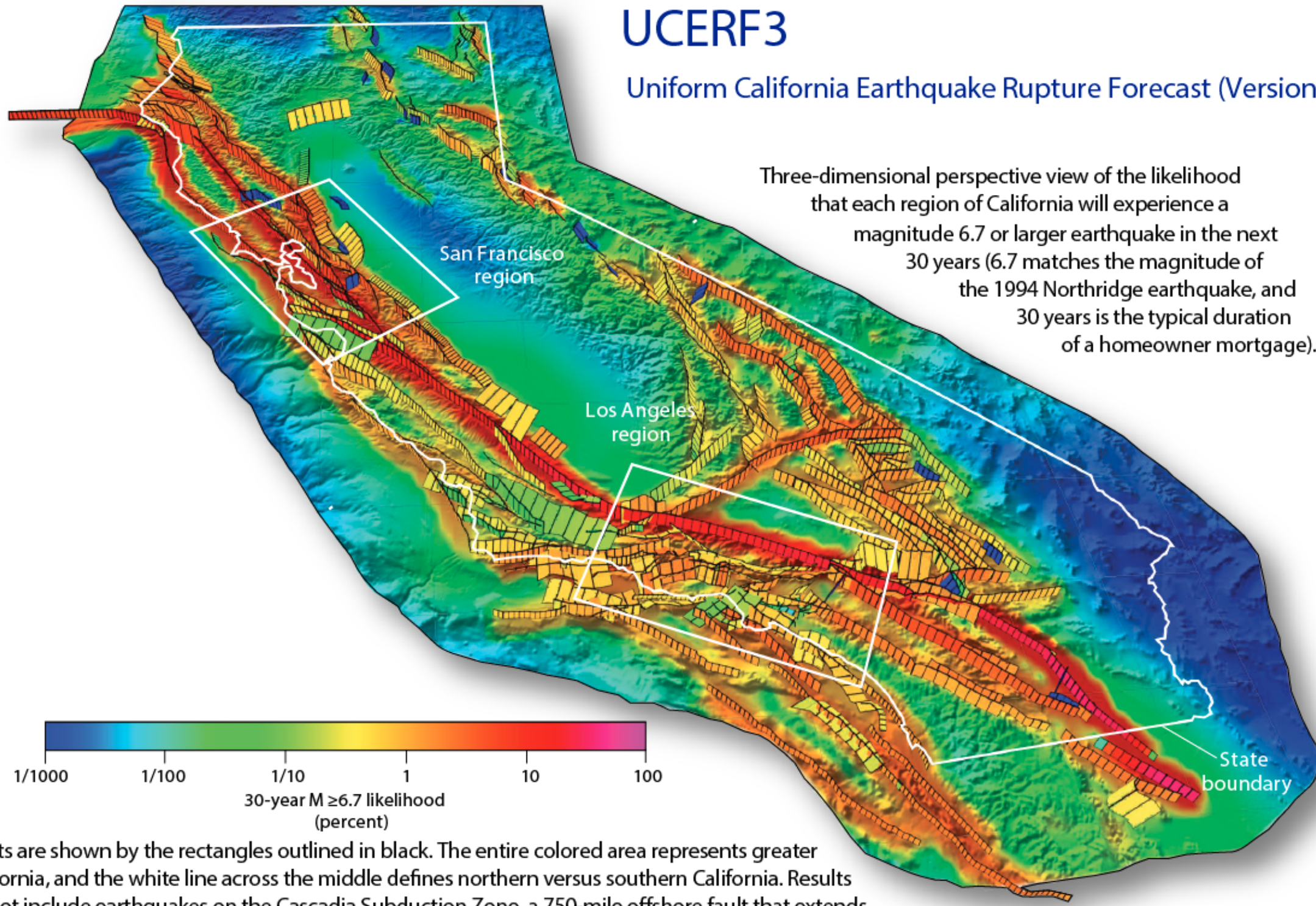
CGS CALIFORNIA GEOLOGICAL SURVEY

CEA CALIFORNIA EARTHQUAKE AUTHORITY™
THE STRENGTH TO REBUILD®

UCERF3

Uniform California Earthquake Rupture Forecast (Version 3)

Three-dimensional perspective view of the likelihood that each region of California will experience a magnitude 6.7 or larger earthquake in the next 30 years (6.7 matches the magnitude of the 1994 Northridge earthquake, and 30 years is the typical duration of a homeowner mortgage).



Faults are shown by the rectangles outlined in black. The entire colored area represents greater California, and the white line across the middle defines northern versus southern California. Results do not include earthquakes on the Cascadia Subduction Zone, a 750-mile offshore fault that extends about 150 miles into California from Oregon and Washington to the north.

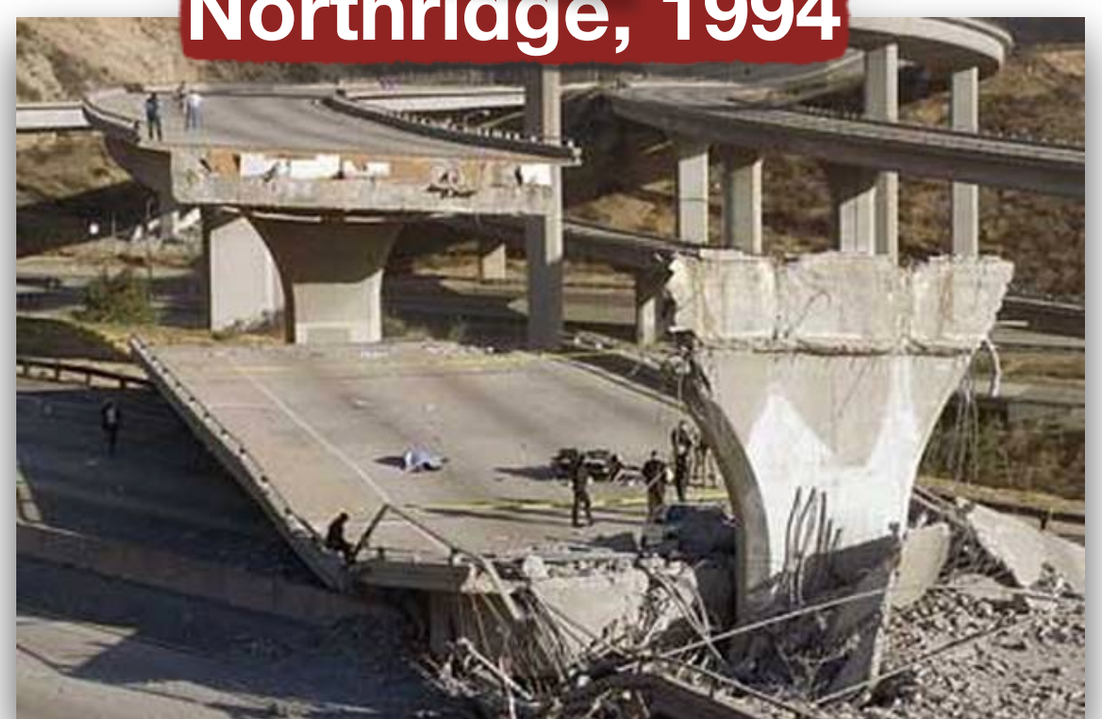
Earthquakes on “blind” faults

Napa, 2014

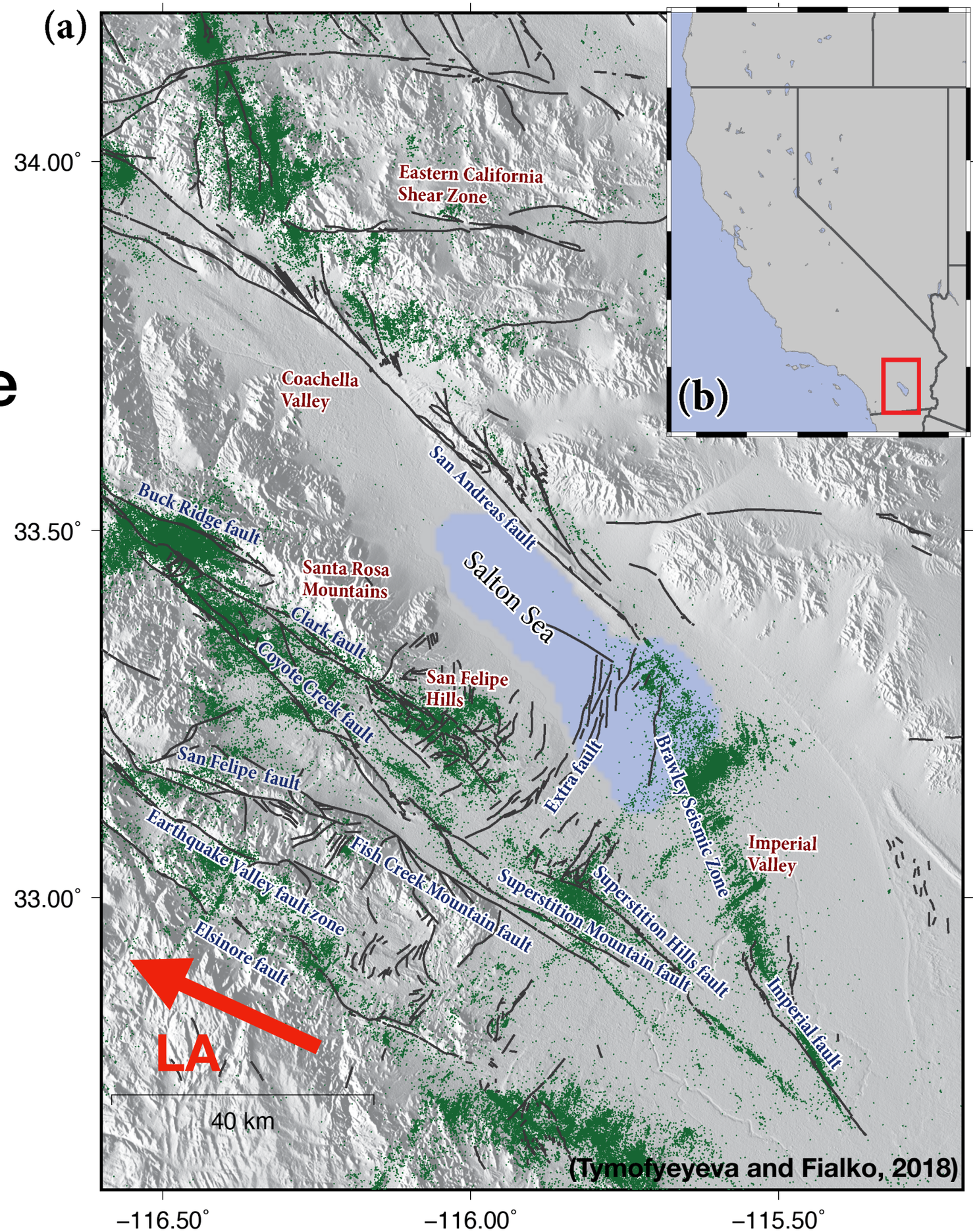
Christchurch, 2011

Haiti, 2010

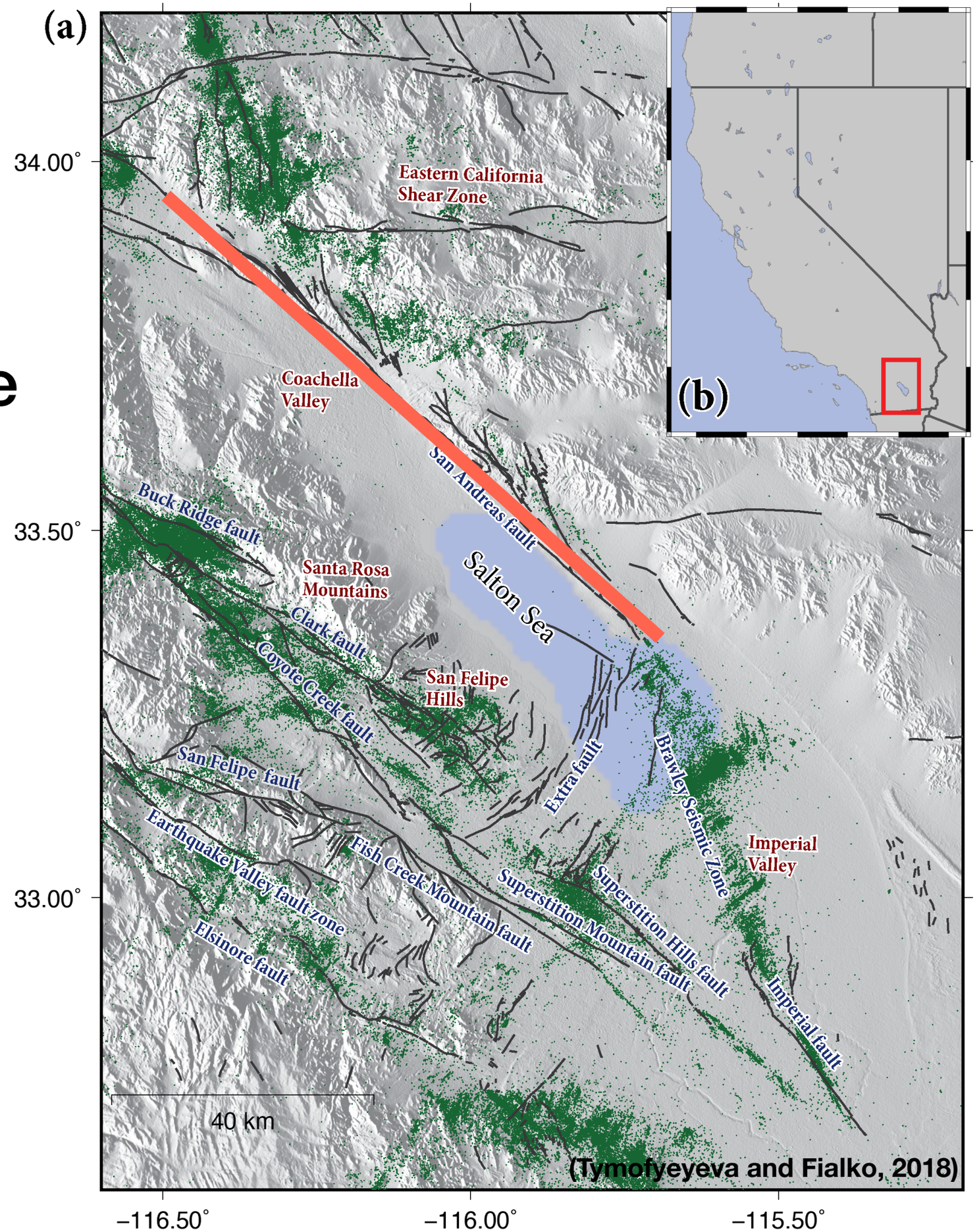
Northridge, 1994



“Blind” fault in the San Jacinto fault zone

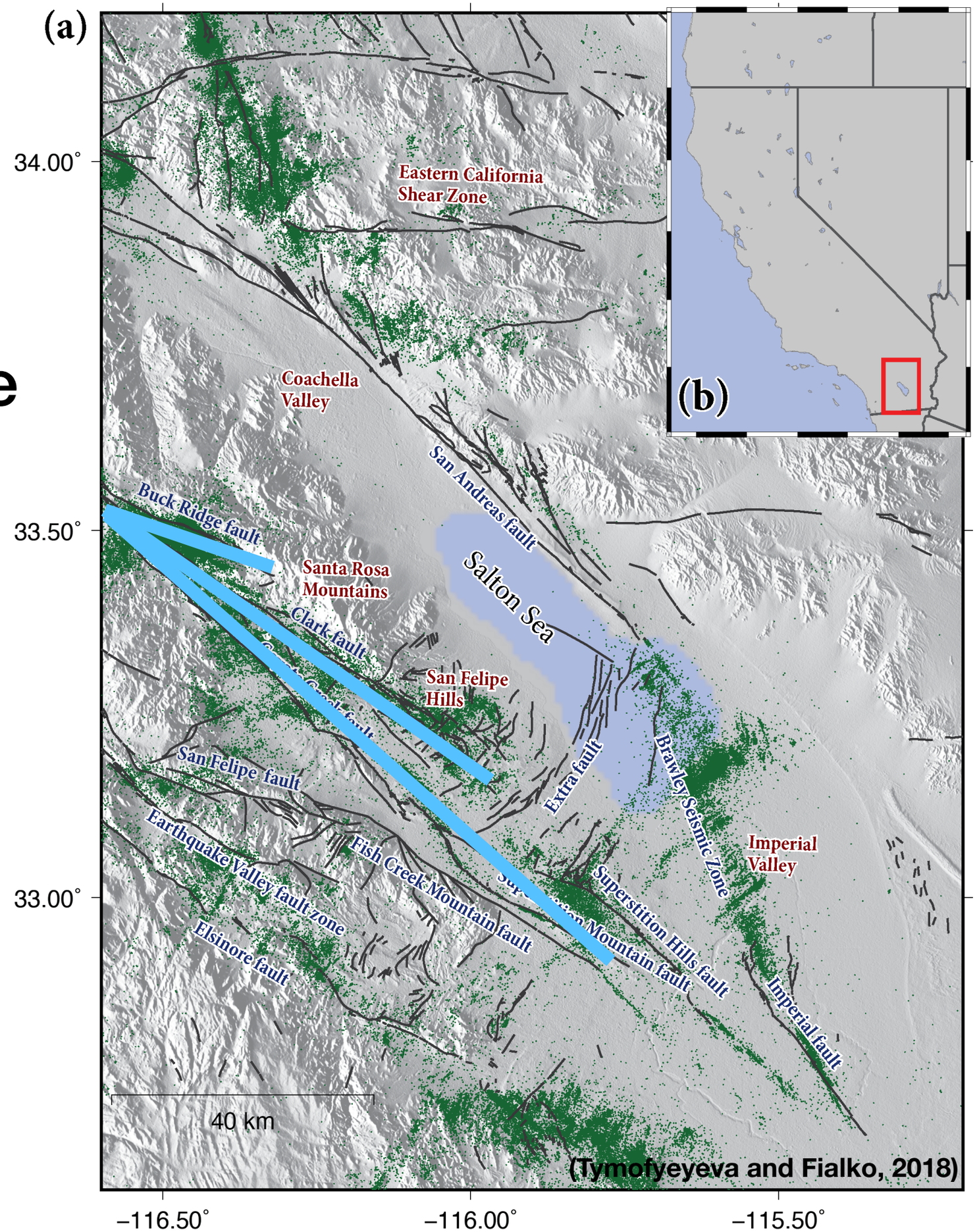


“Blind” fault in the San Jacinto fault zone

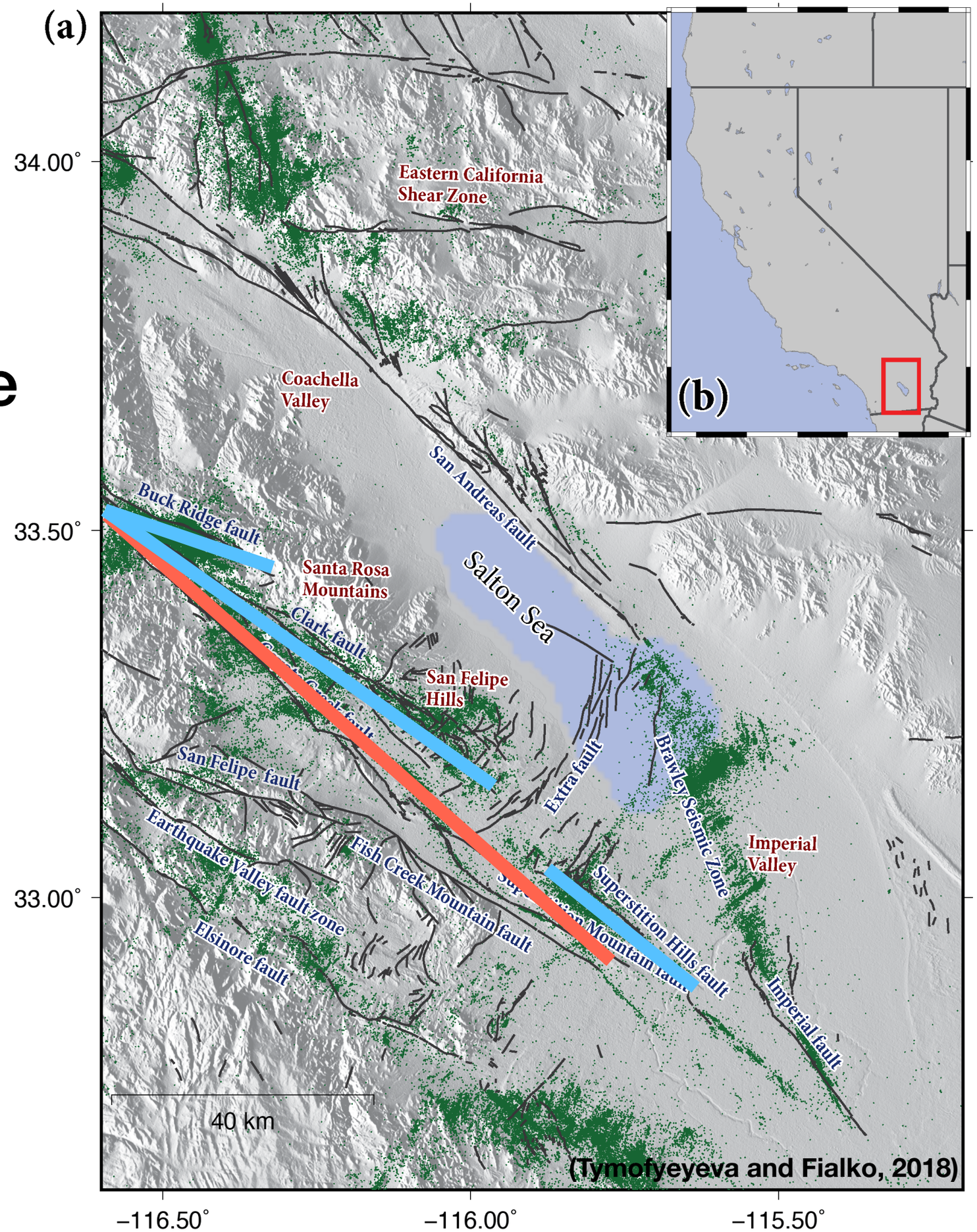


(Tymofyeyeva and Fialko, 2018)

“Blind” fault in the San Jacinto fault zone

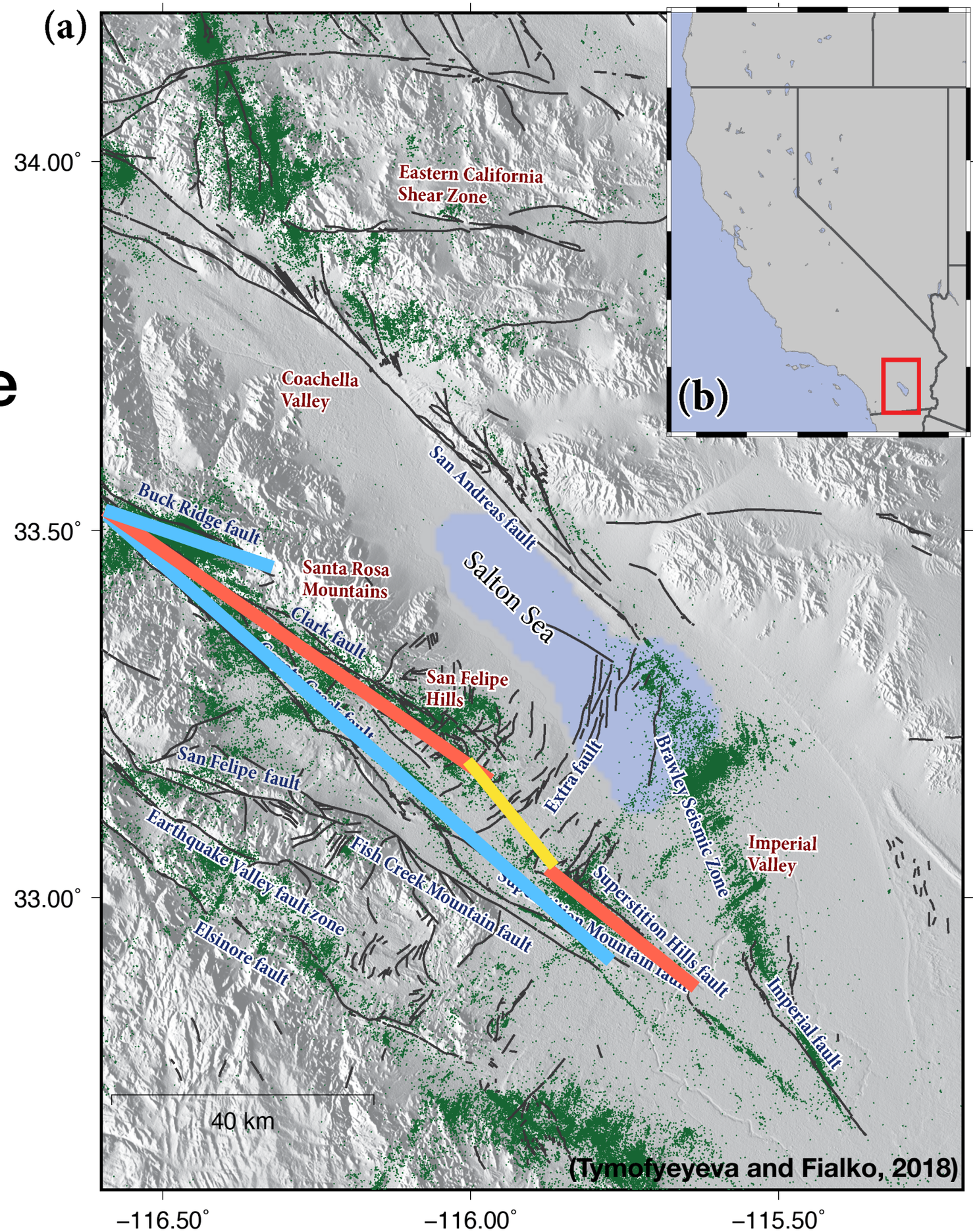


“Blind” fault in the San Jacinto fault zone

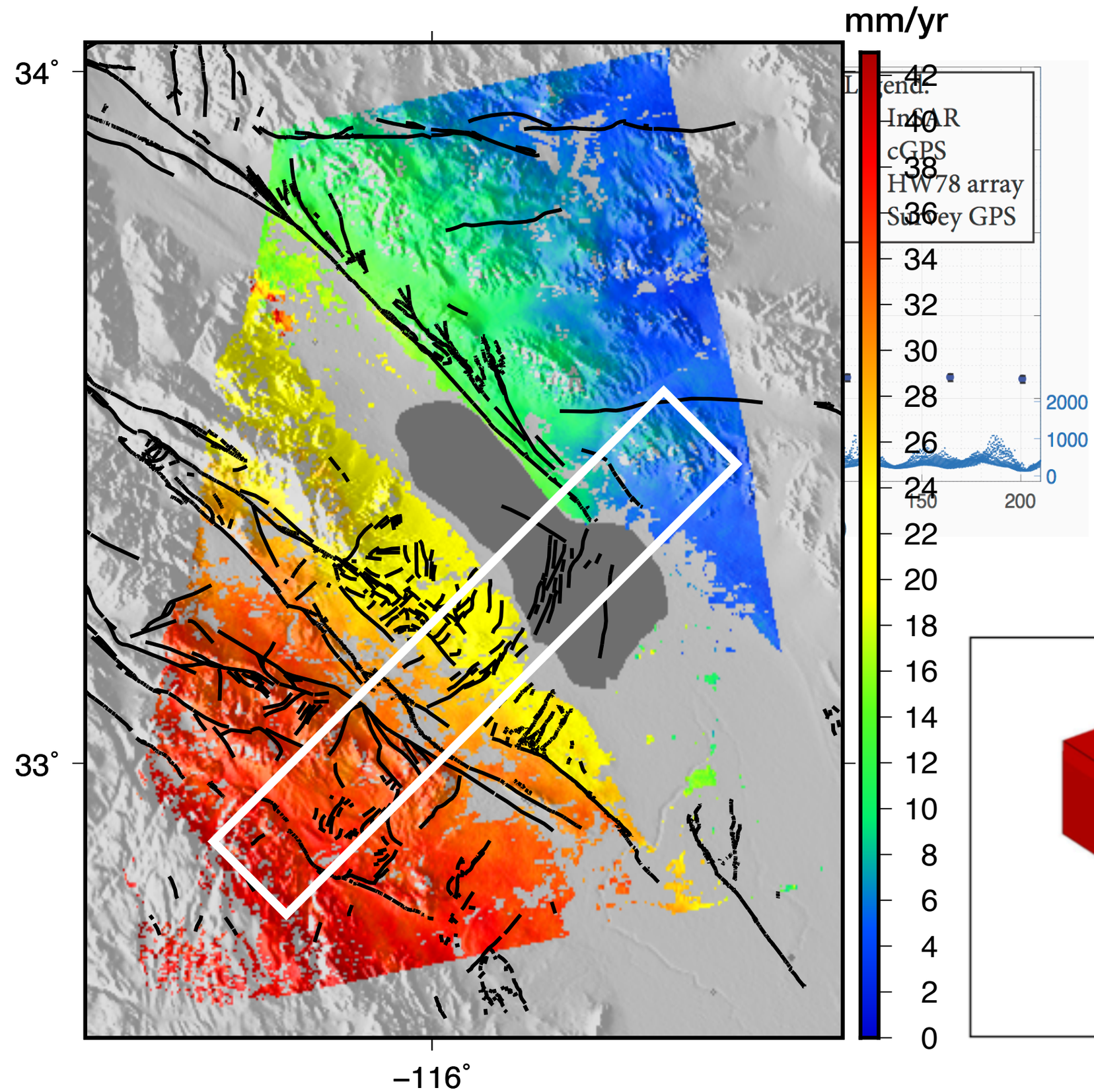


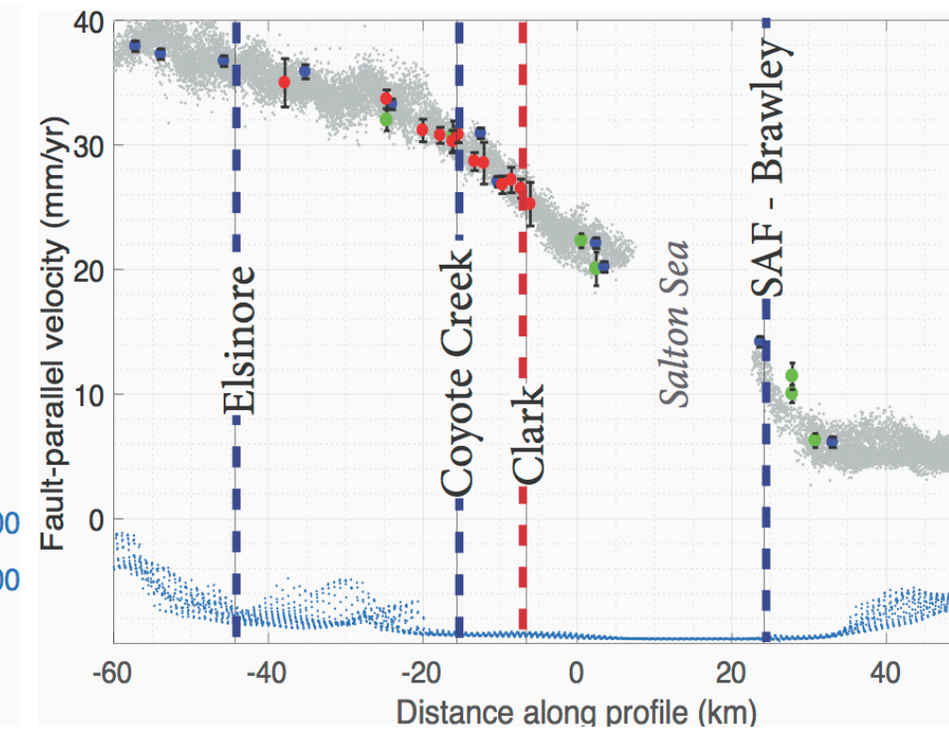
(Tymofyeyeva and Fialko, 2018)

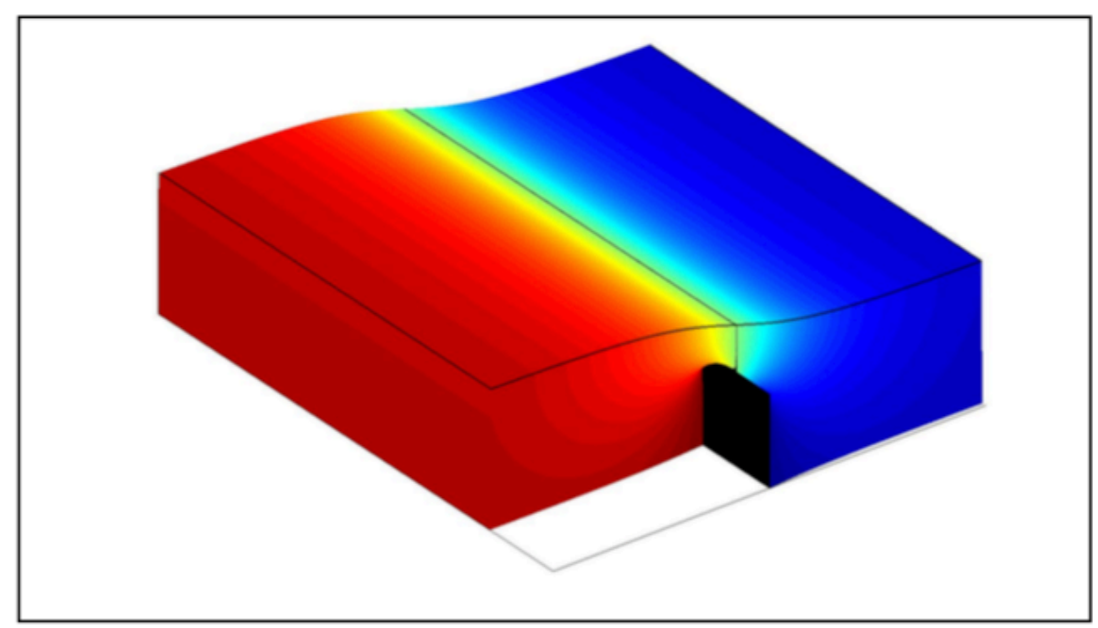
“Blind” fault in the San Jacinto fault zone



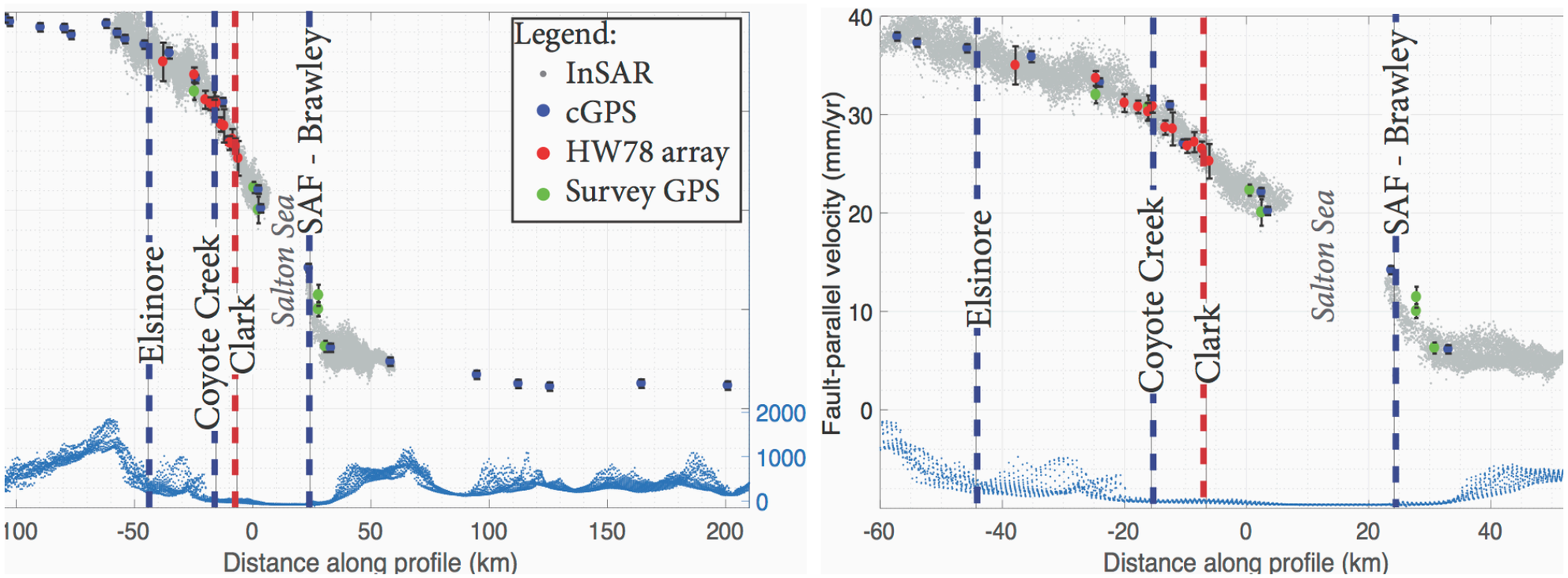
SURFACE VELOCITIES: 2002–2010 (ENVISAT)



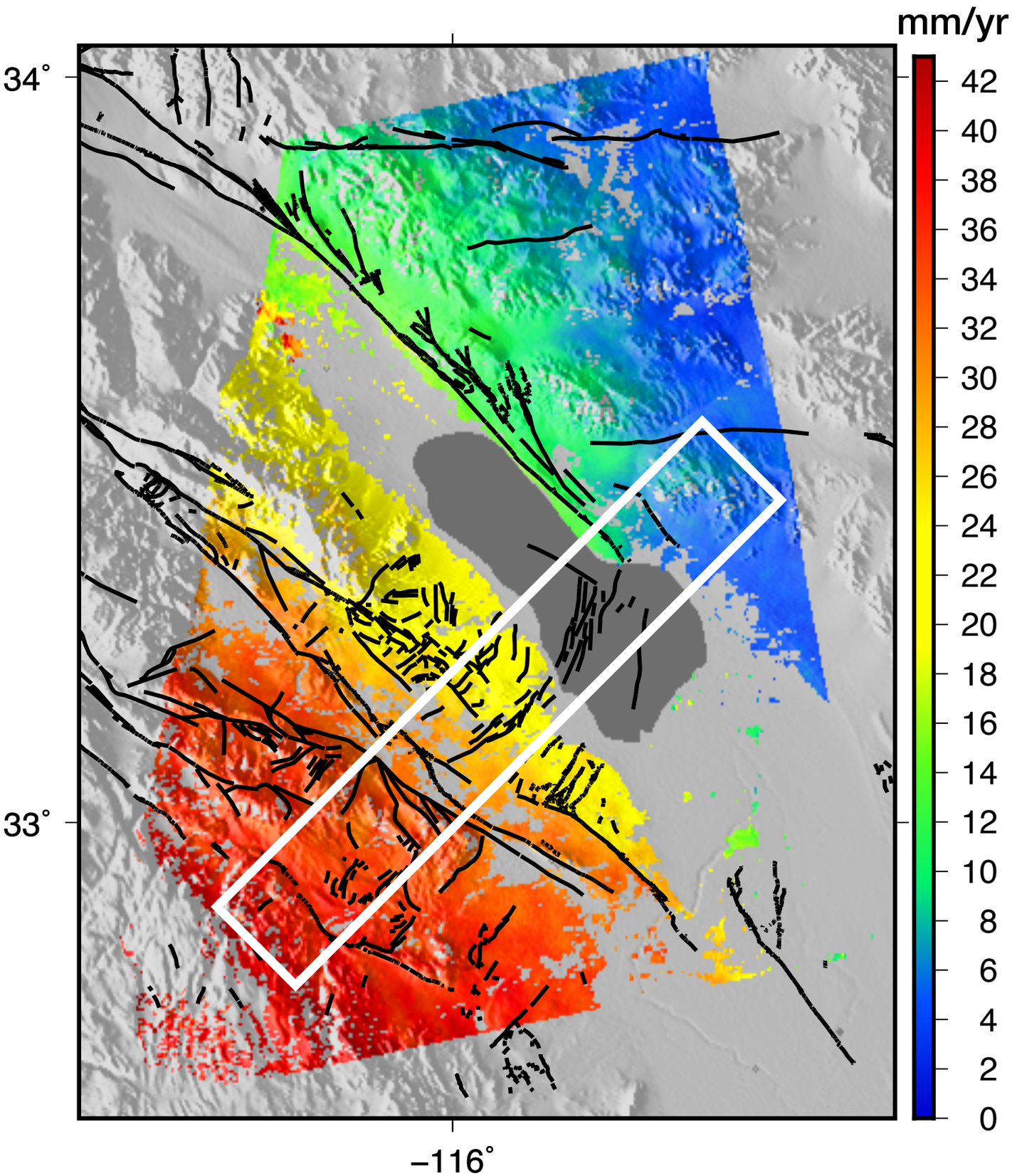


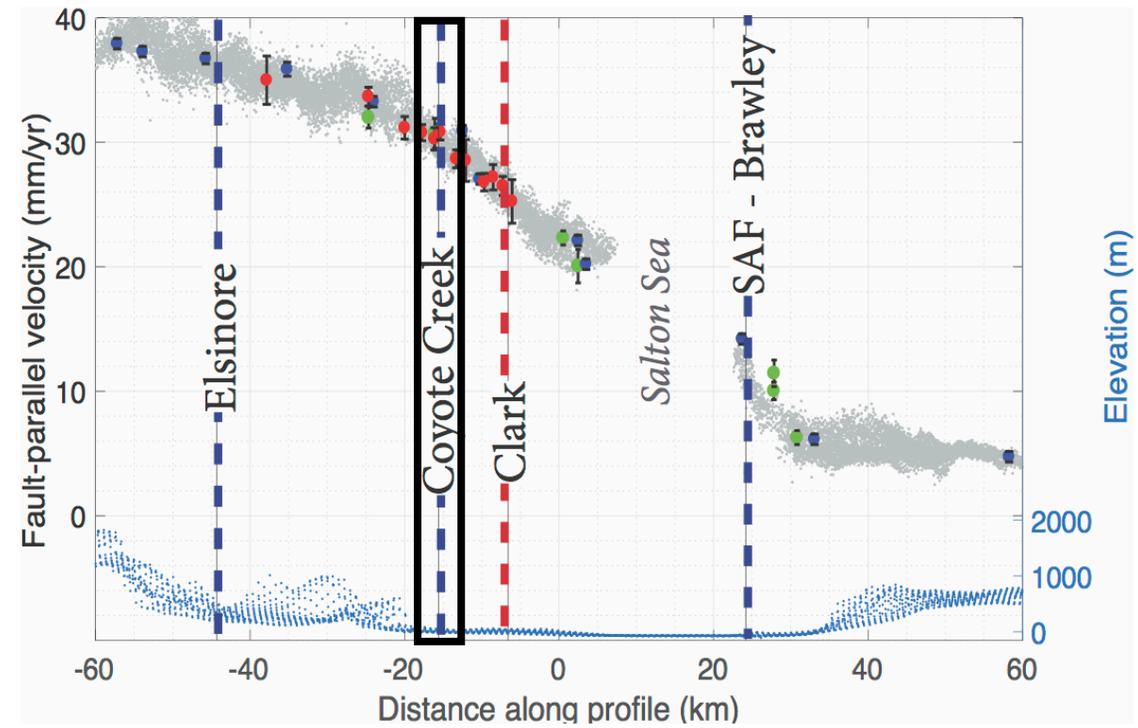


(Tymofyeyeva and Fialko, 2018)

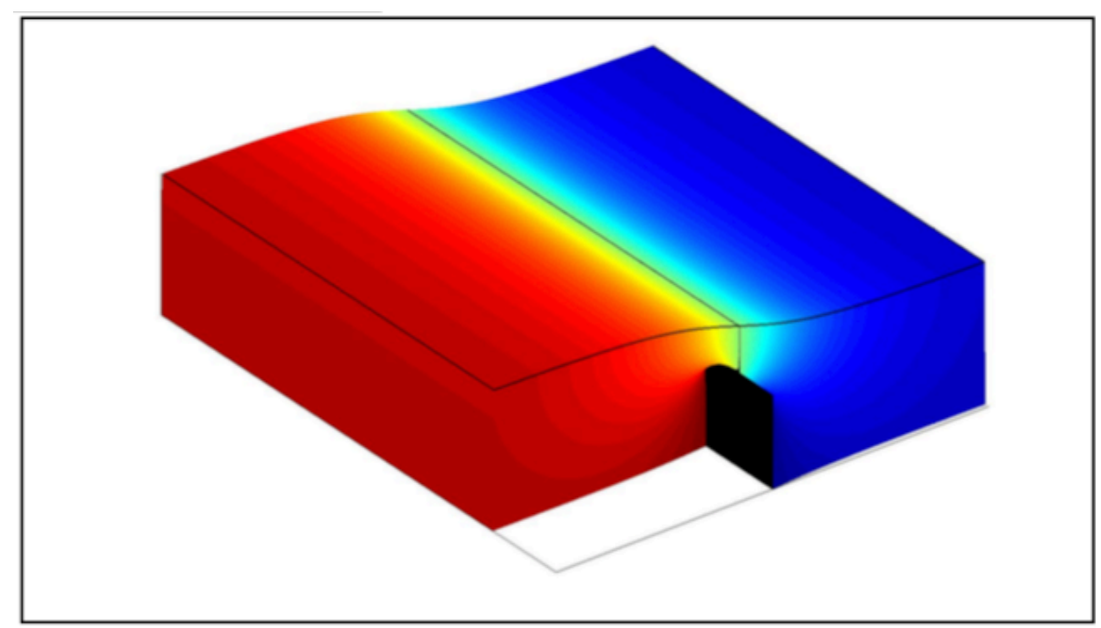

Legend:
InSAR
cGPS
HW78 array
Survey GPS
Elsinore
Coyote Creek
Clark
Salton Sea
SAF - Brawley
2000
1000
0
100
-50
0
50
100
150
200
Distance along profile (km)
Fault-parallel velocity (mm/yr)
40
30
20
10
0
-60
-40
-20
0
20
40
Distance along profile (km)

SURFACE VELOCITIES: 2002–2010 (ENVISAT)



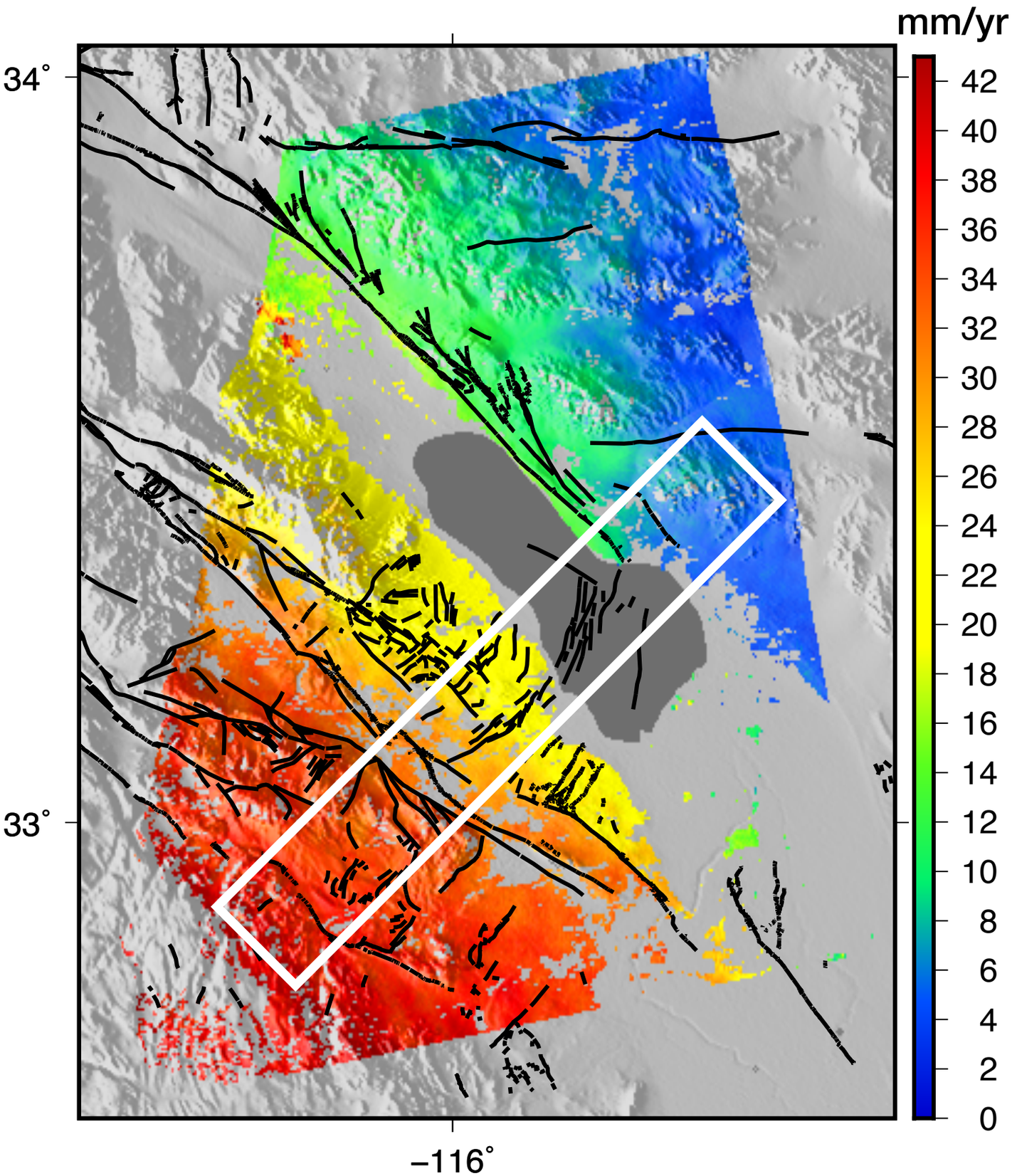


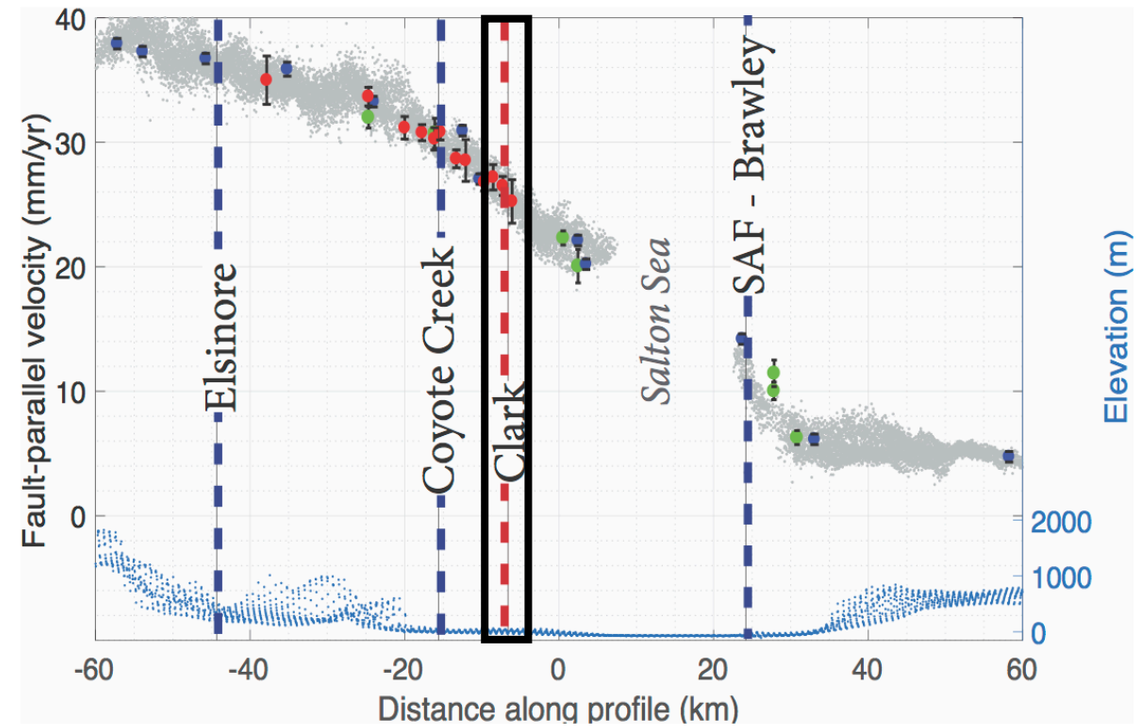
Expected interseismic deformation:



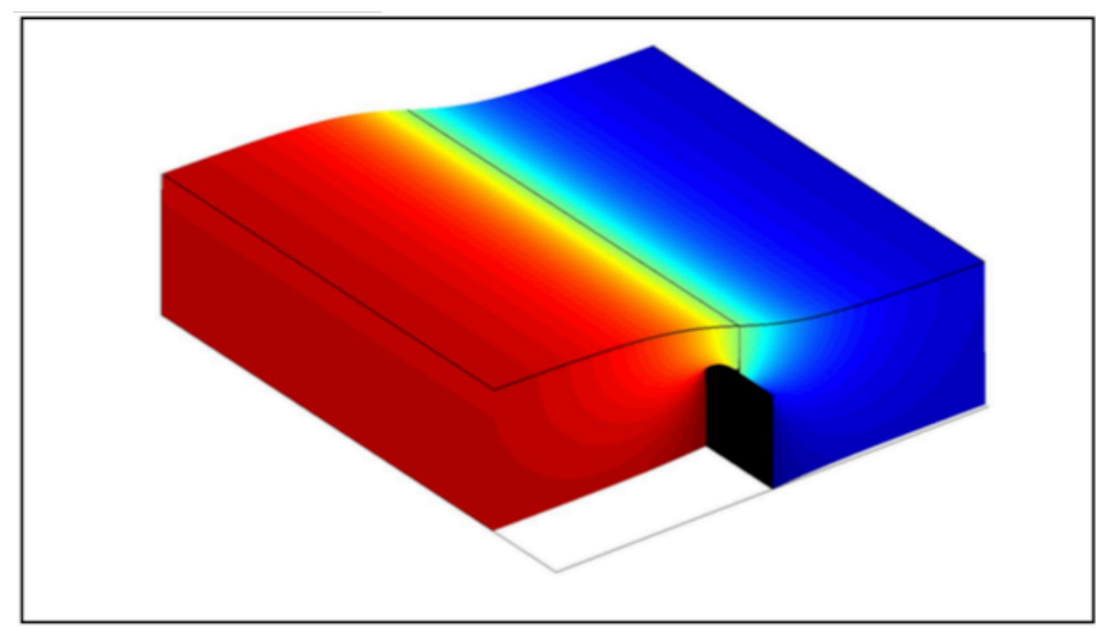
(Tymofyeyeva and Fialko, 2018)

SURFACE VELOCITIES: 2002–2010 (ENVISAT)





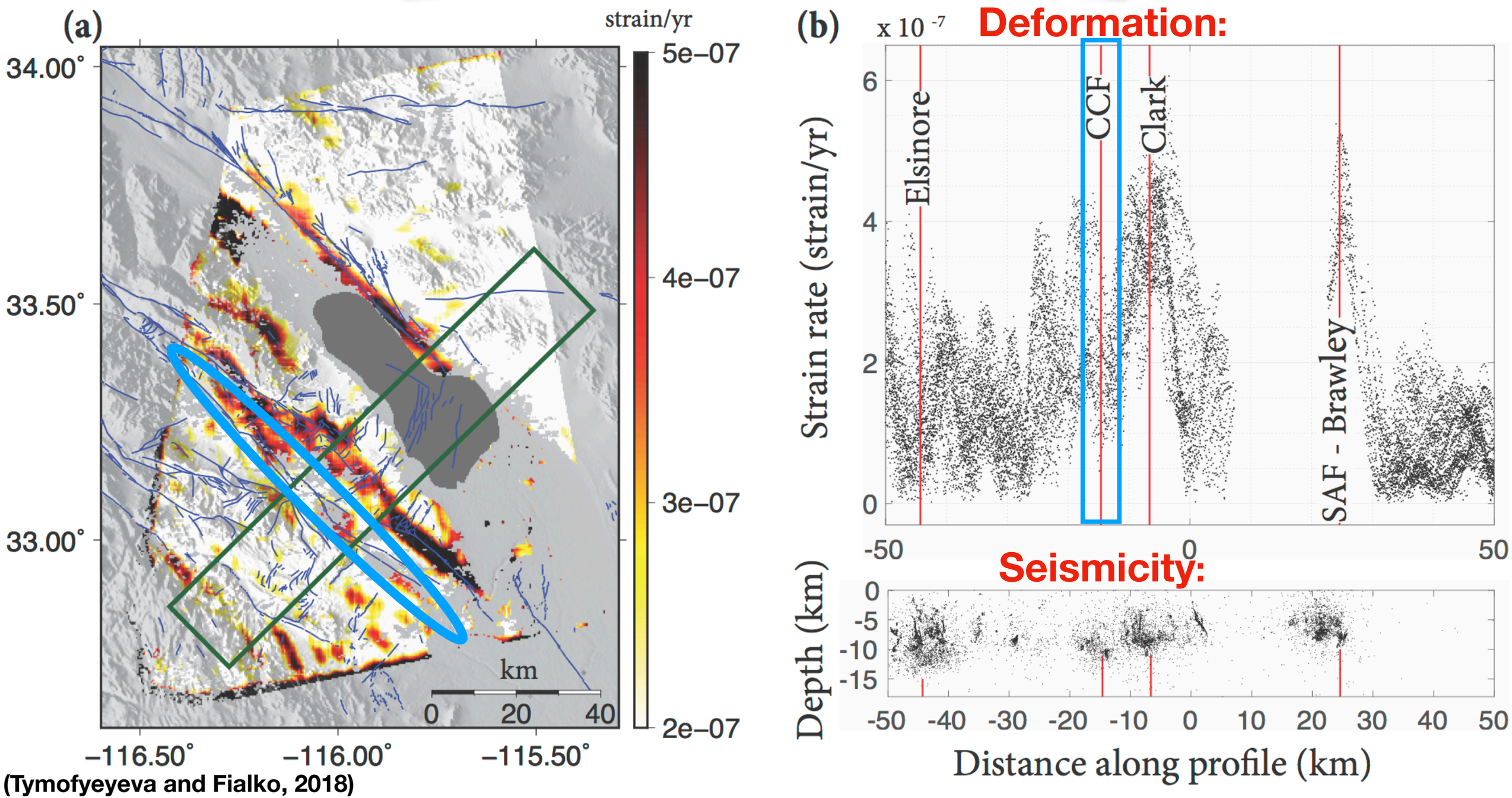
Expected interseismic deformation:



(Tymofyeyeva and Fialko, 2018)

STRAIN RATES: 2002–2010 (ENVISAT)

$$\dot{\varepsilon}_{max} = \frac{1}{2}\sqrt{\left(\frac{\partial v_E}{\partial N} + \frac{\partial v_N}{\partial E}\right)^2 + \left(\frac{\partial v_E}{\partial E} - \frac{\partial v_N}{\partial N}\right)^2}$$



(Tymofyeyeva and Fialko, 2018)

STRAIN RATES: 2002–2010 (ENVISAT)

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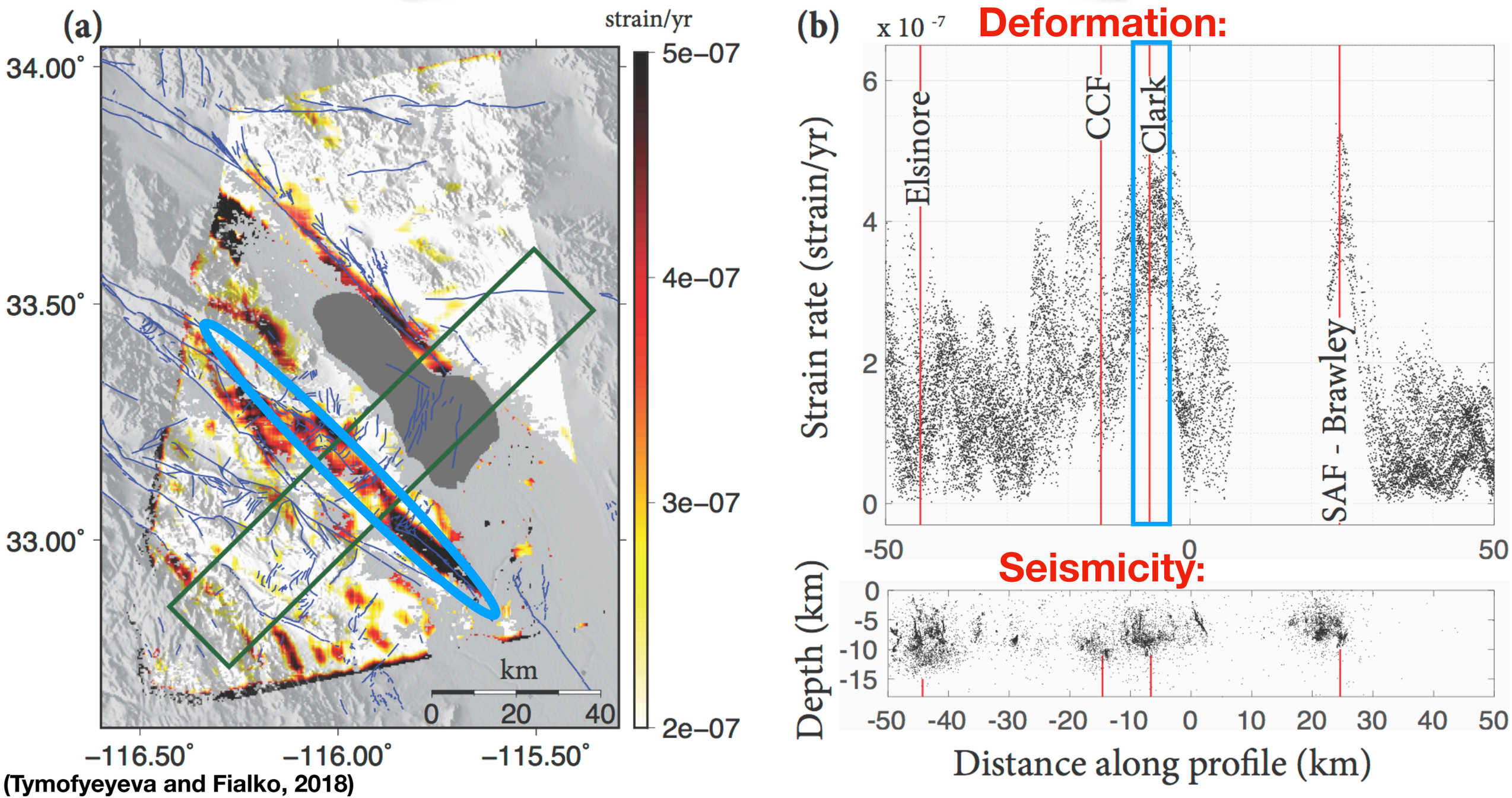
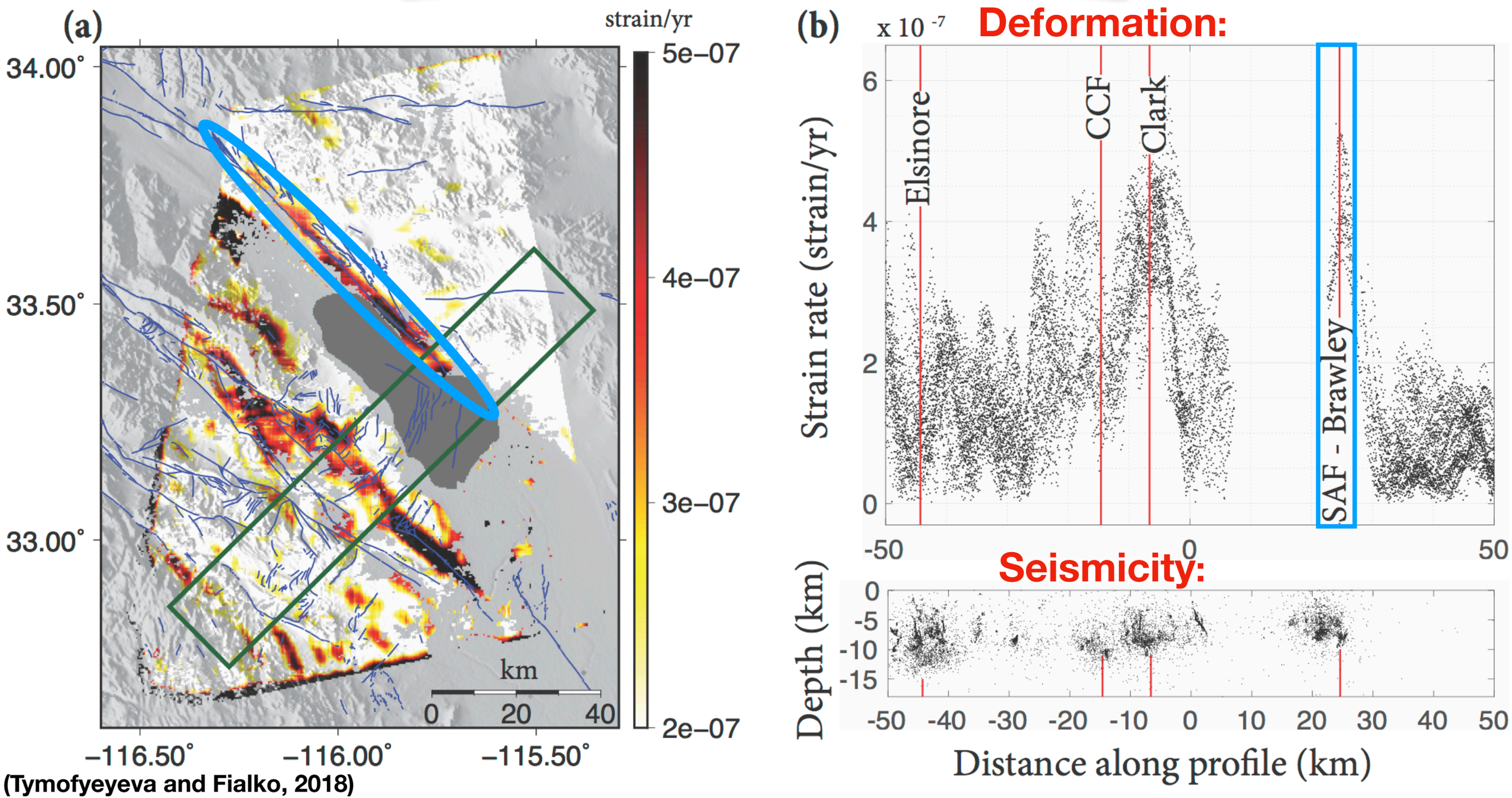


(Tymofyeyeva and Fialko, 2018)

STRAIN RATES: 2002–2010 (ENVISAT)

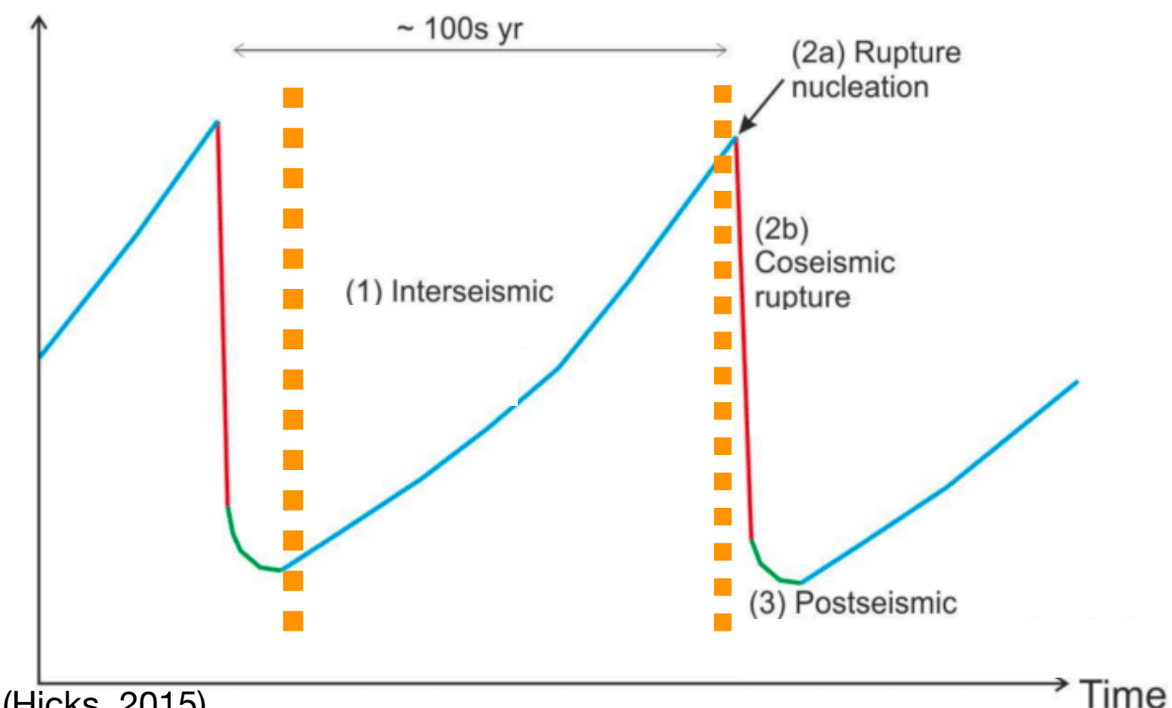
$$\dot{\varepsilon}_{max} = \frac{1}{2}\sqrt{\left(\frac{\partial v_E}{\partial N} + \frac{\partial v_N}{\partial E}\right)^2 + \left(\frac{\partial v_E}{\partial E} - \frac{\partial v_N}{\partial N}\right)^2}$$



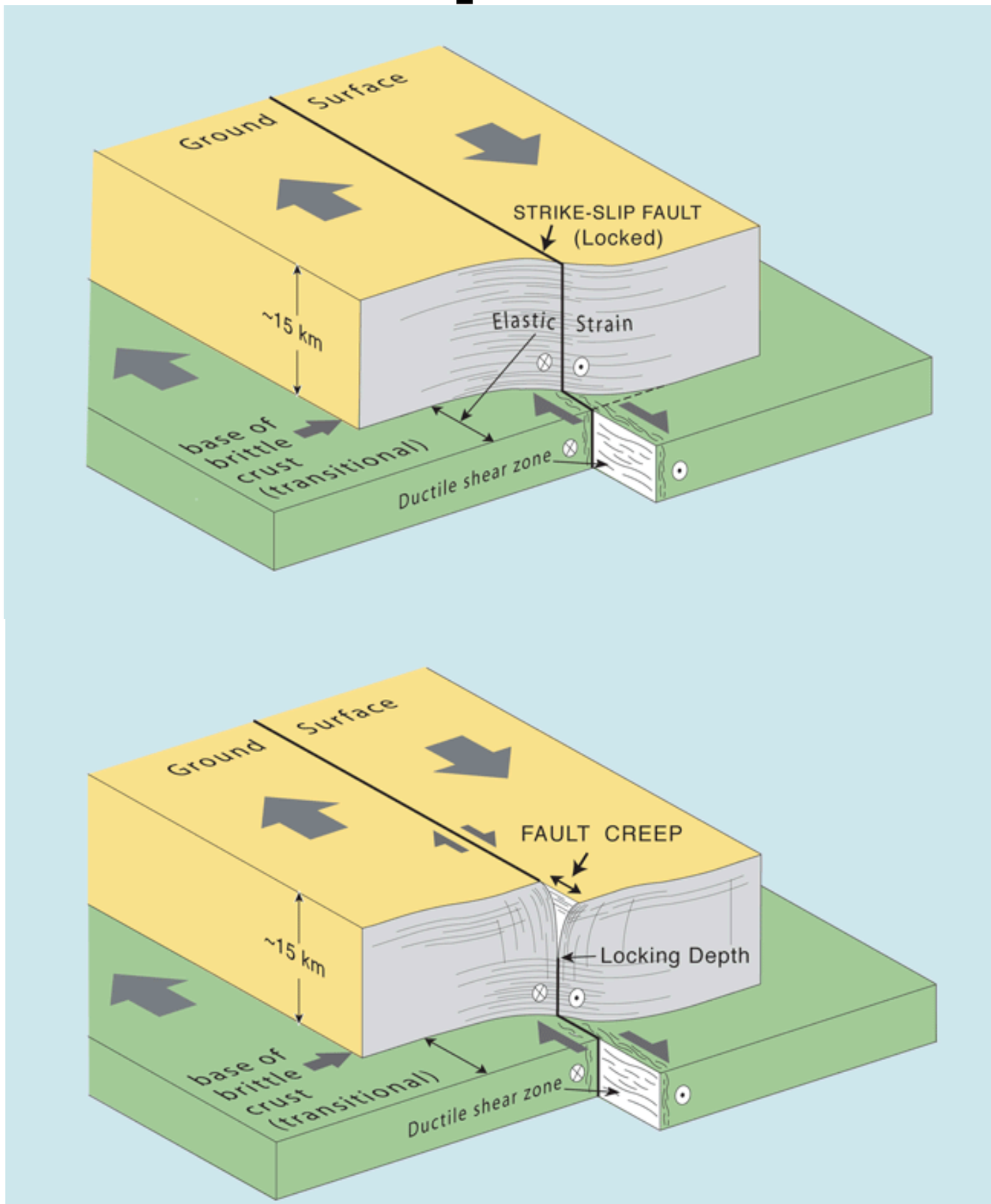
(Tymofyeyeva and Fialko, 2018)

Shallow creep

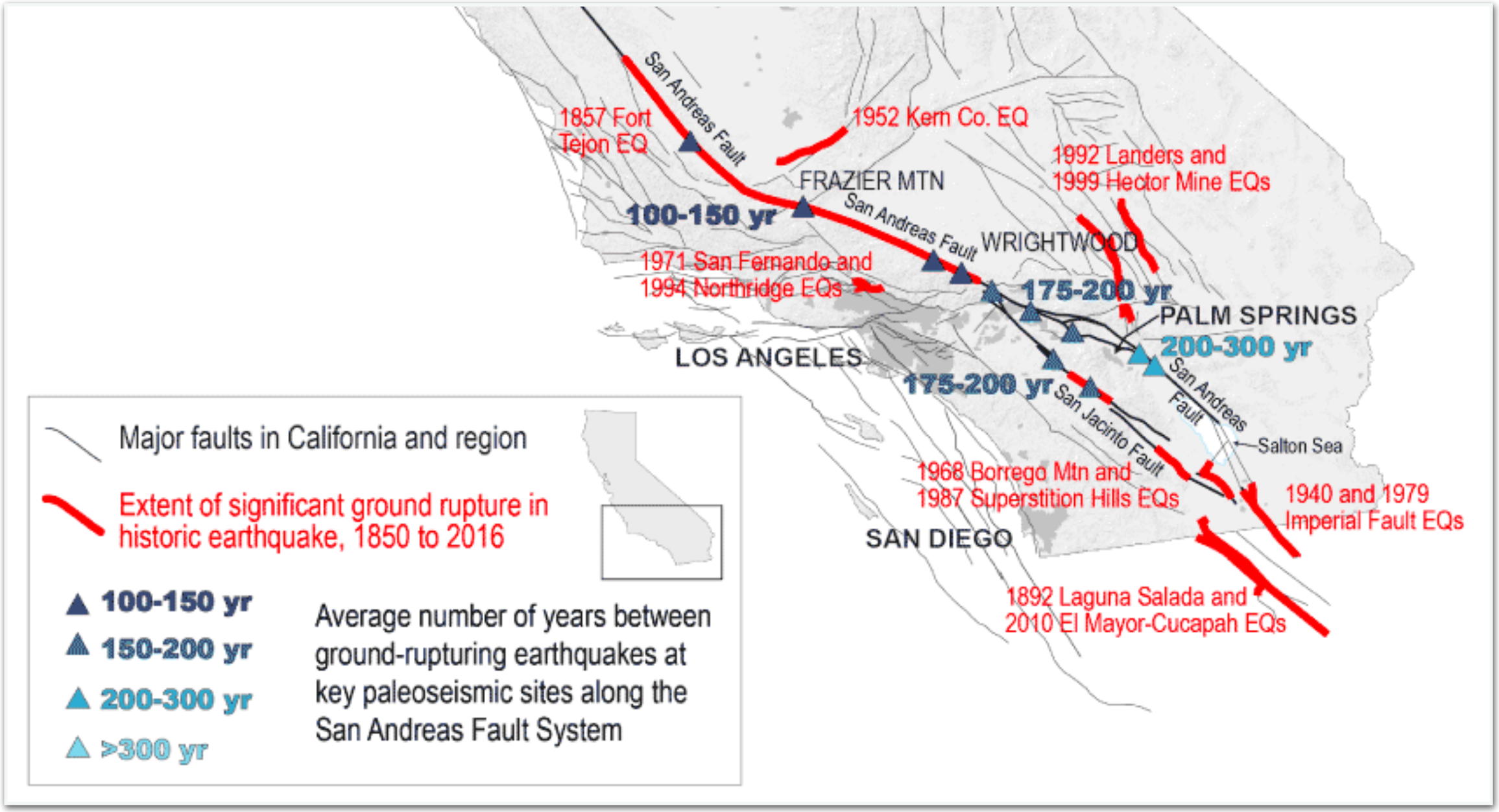
- Happens during the interseismic period.
- Evidence shows that shallow creep can resemble a series of slow, silent earthquakes.



(Hicks, 2015)

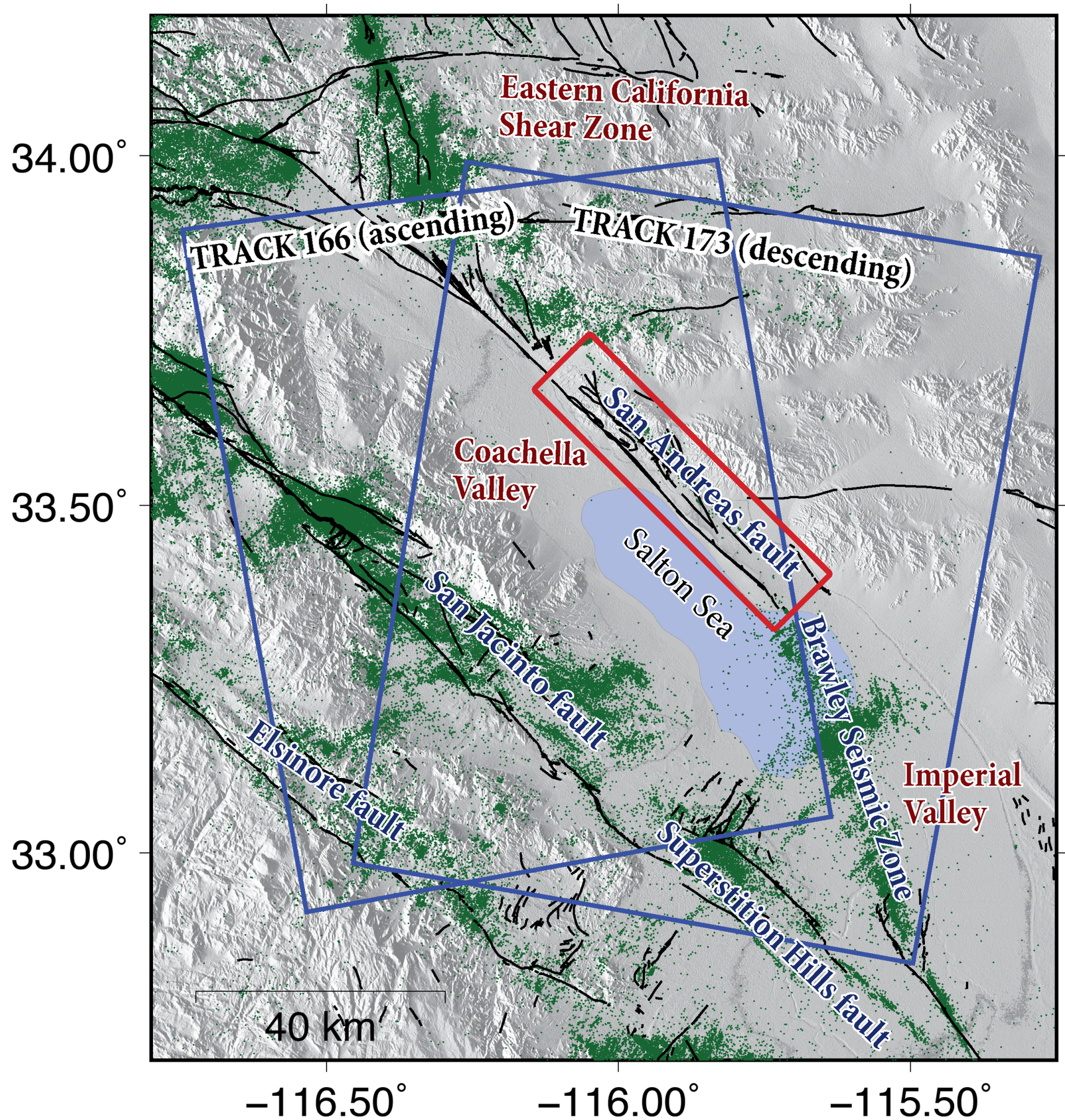


Historic earthquakes on the Southern San Andreas fault



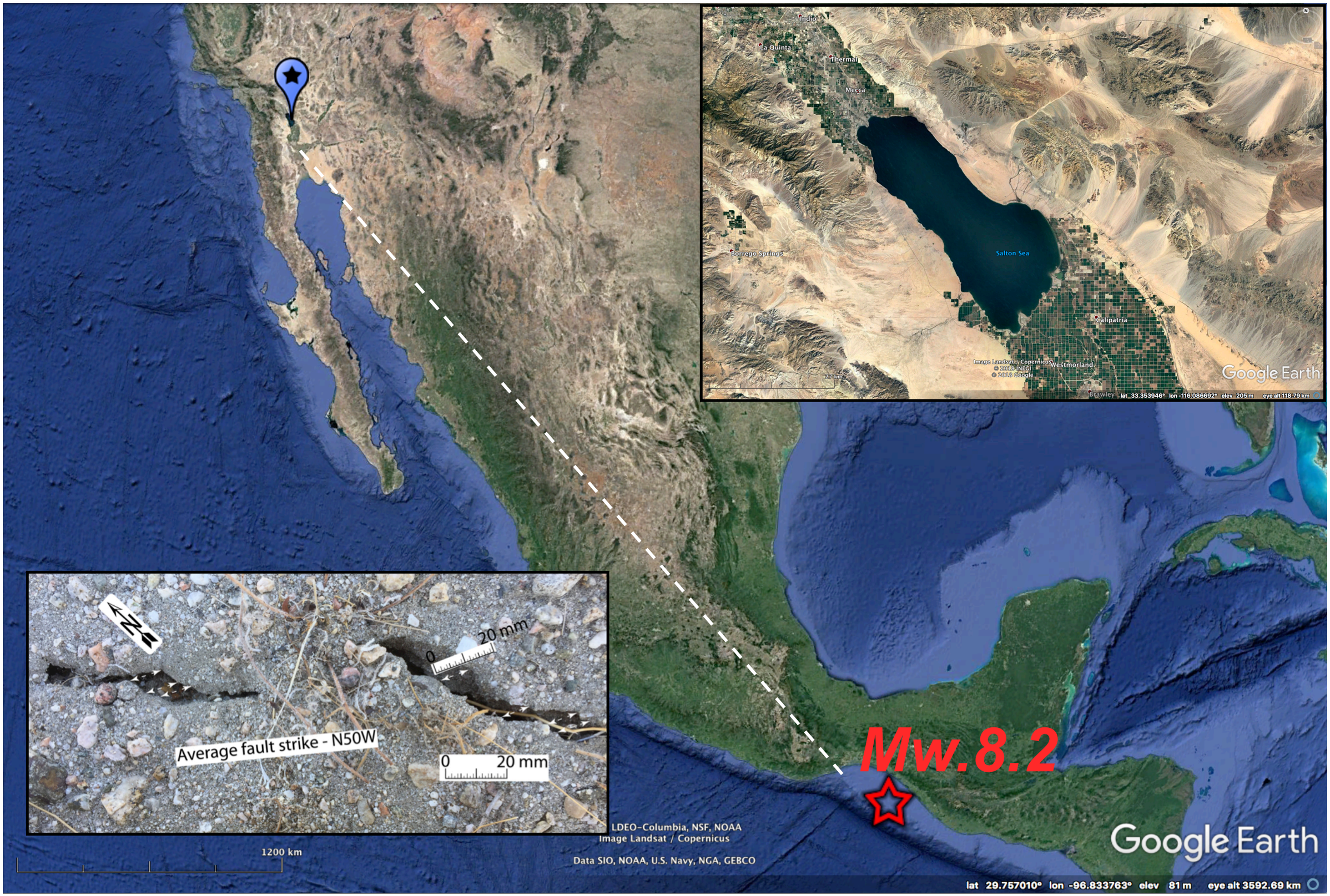
(earthquakes.usgs.gov)

Shallow creep on the Southern San Andreas fault



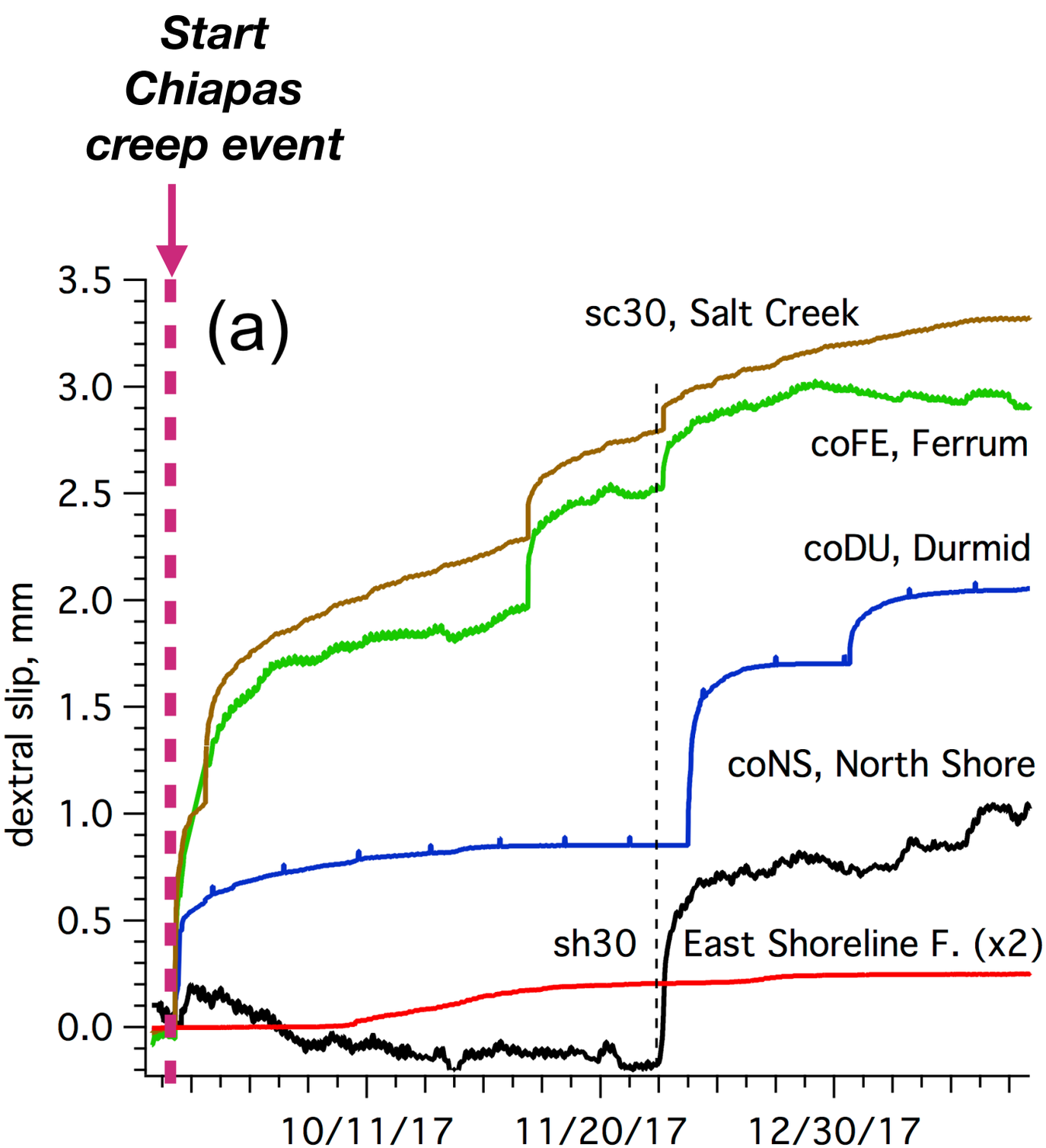
(Tymofyeyeva et al., JGR, in review)

September 7, 2017



Katia Tymofyeyeva, Yuri Fialko, Junle Jiang, Xiaohua Xu, Roger Bilham, David Sandwell, Thomas Rockwell, Chelsea Blanton, Allen Gontz,(in review)

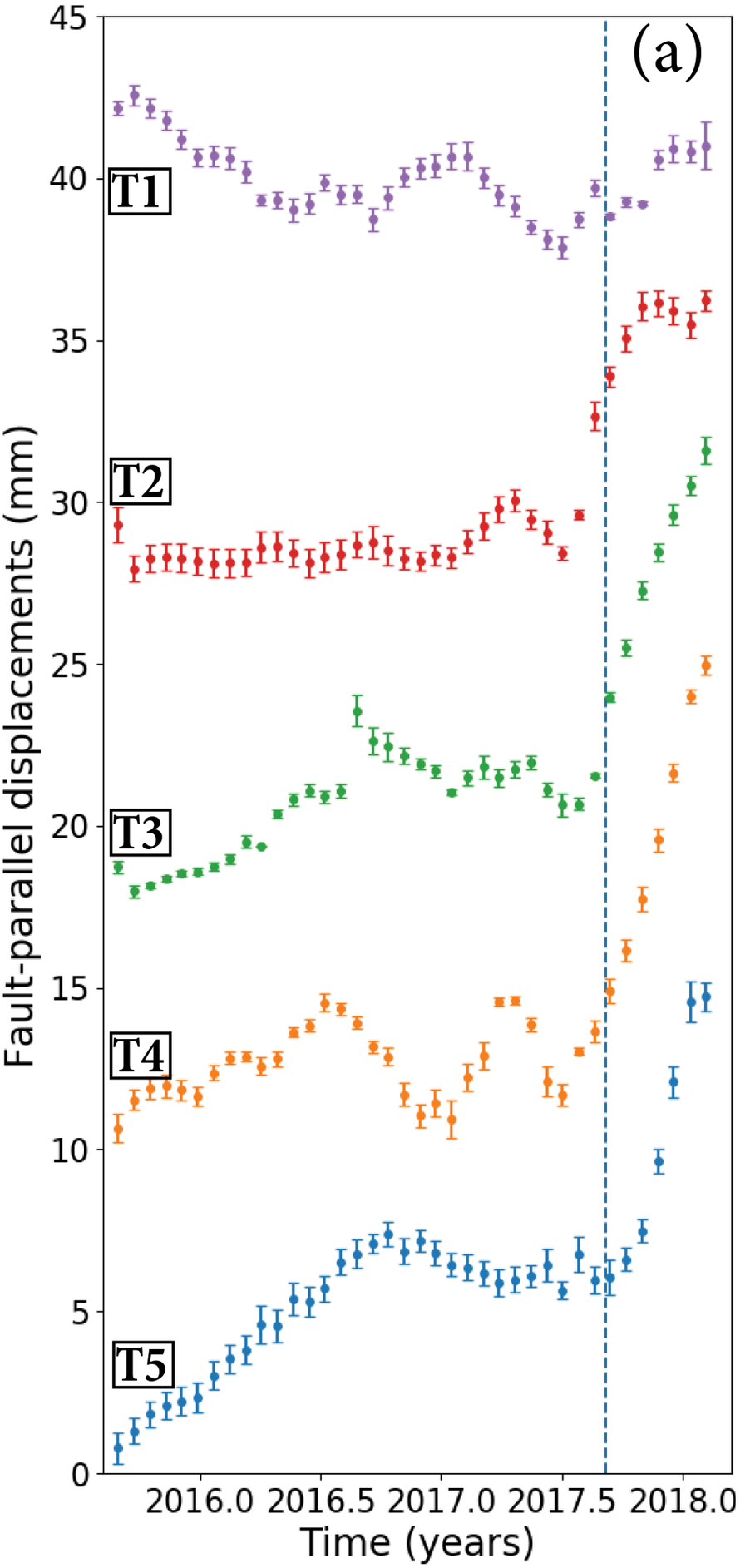
Creepmeter measurements

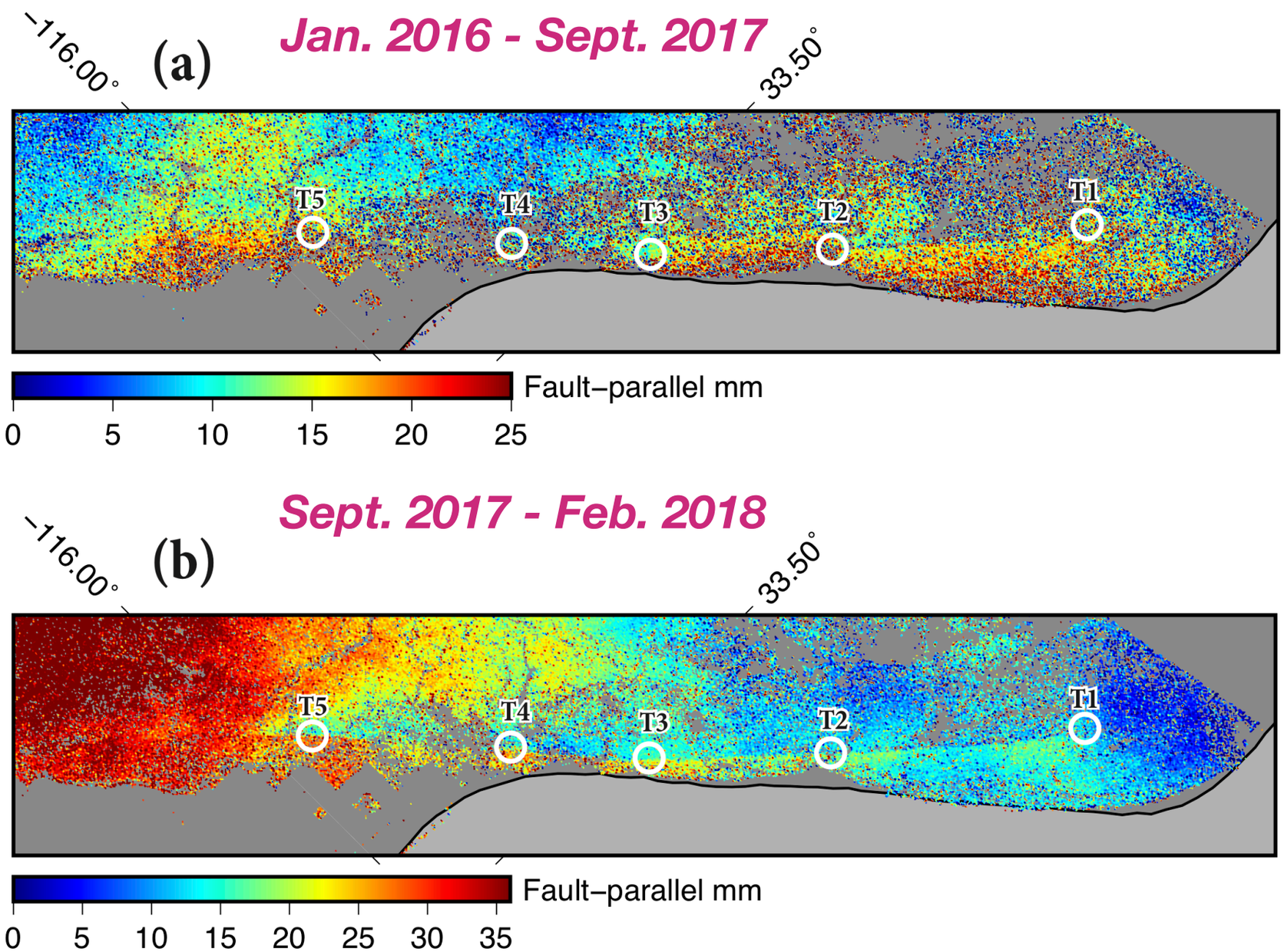


(Tymofyeyeva et al., JGR, in review)

InSAR time series

- Prior to the Sept. 2017 event, creep signal is almost nonexistent.

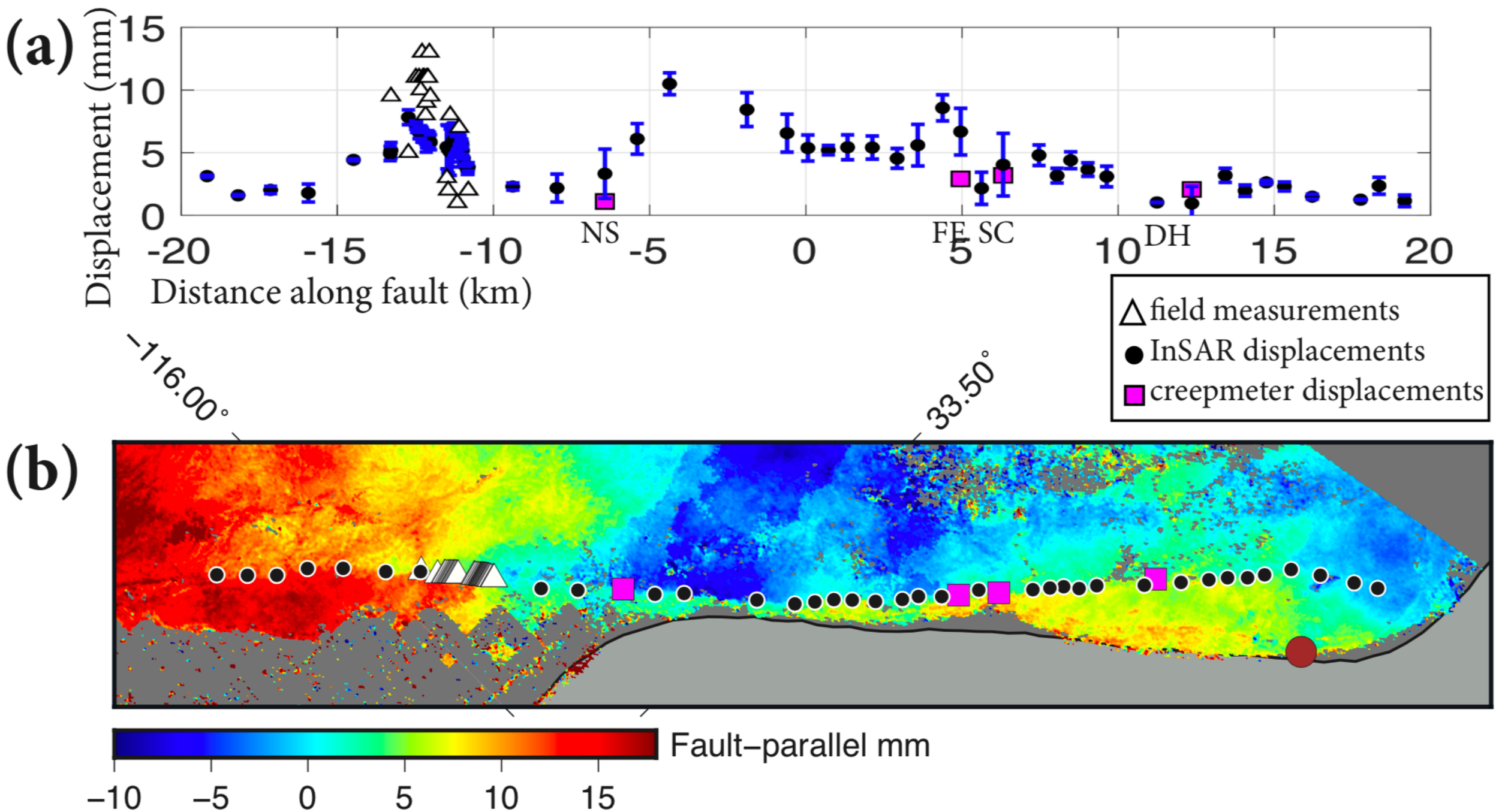




(Tymofyeyeva et al., JGR, in review)

Variable slip along the fault

- The slow slip event produced surface offsets on the order of 4-12mm, with significant variations in slip along-strike.



(Tymofyeyeva et al., JGR, in review)

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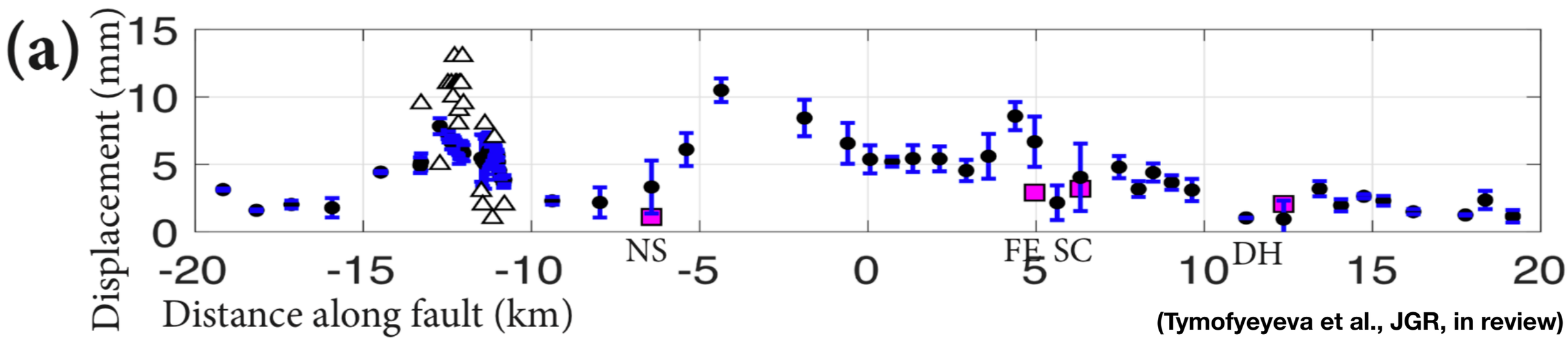
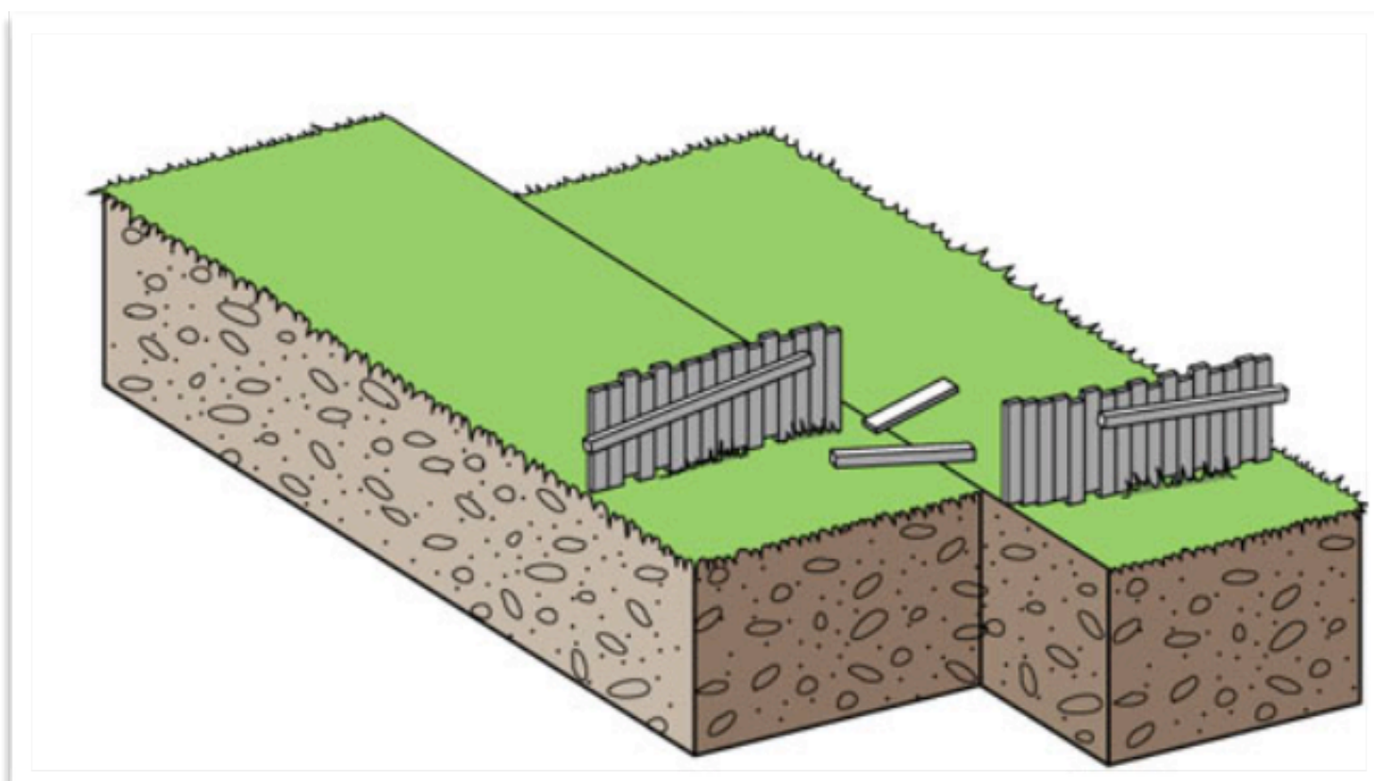
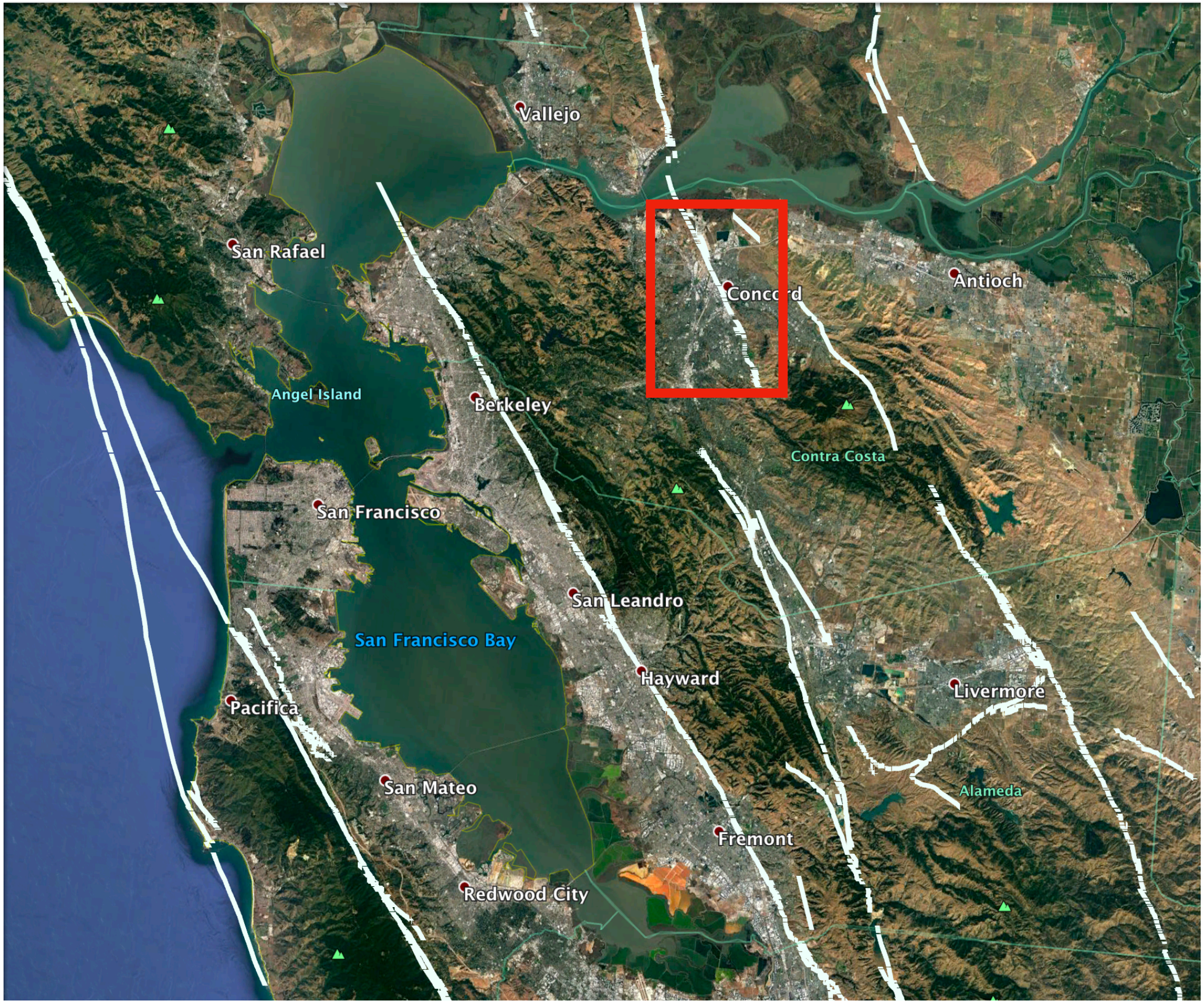


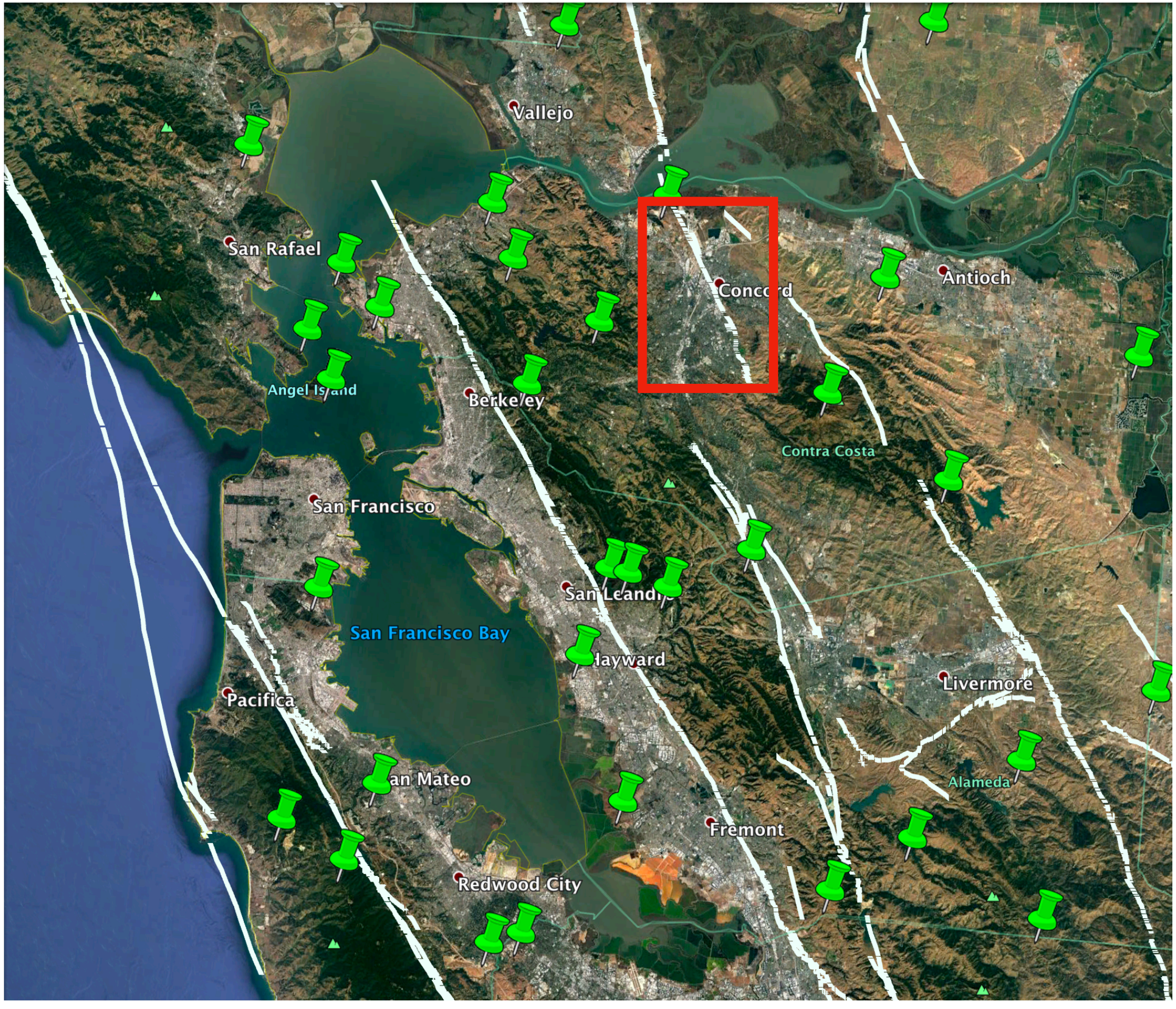
(Tymofyeyeva et al., JGR, in review)



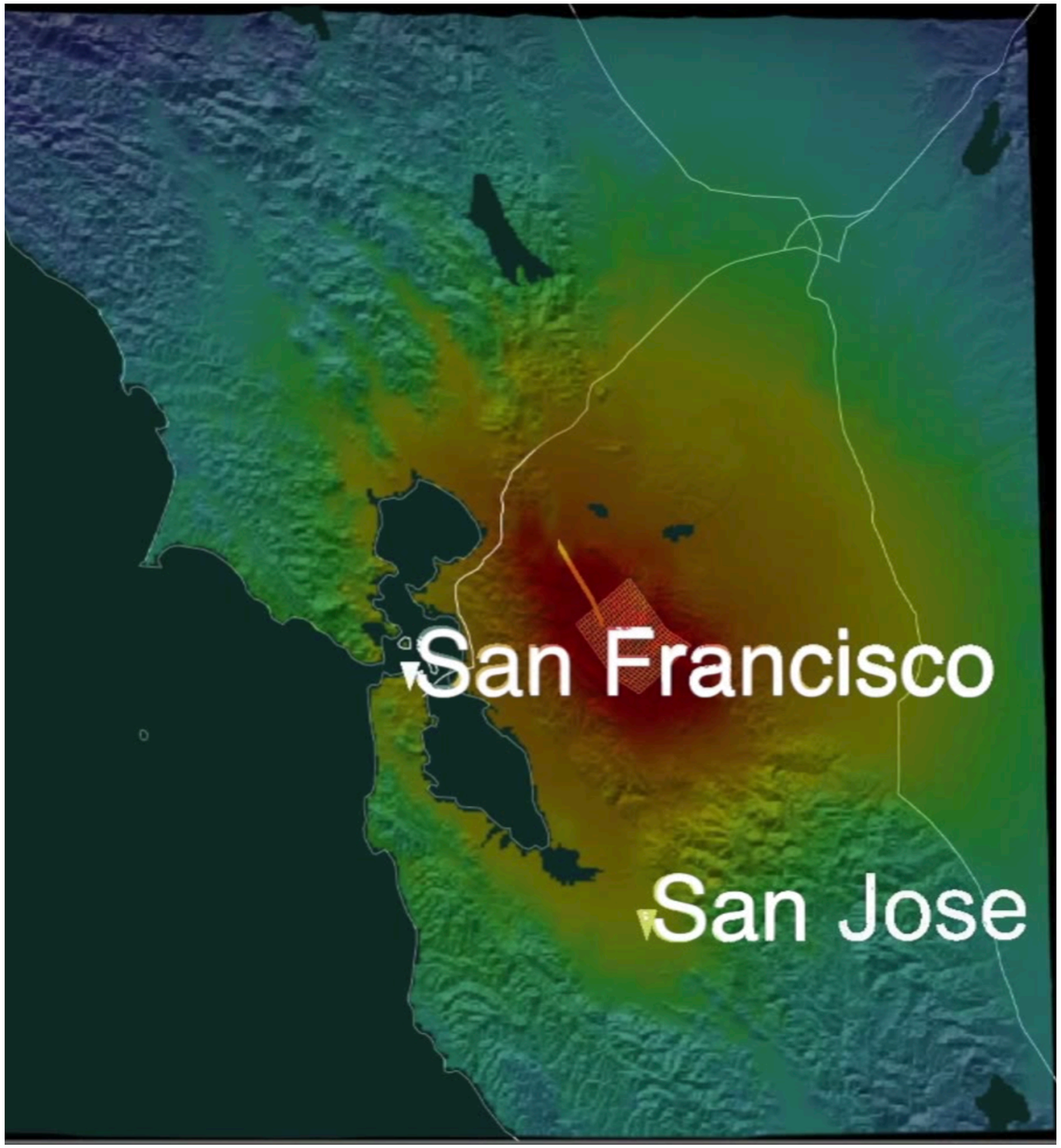
Concord fault

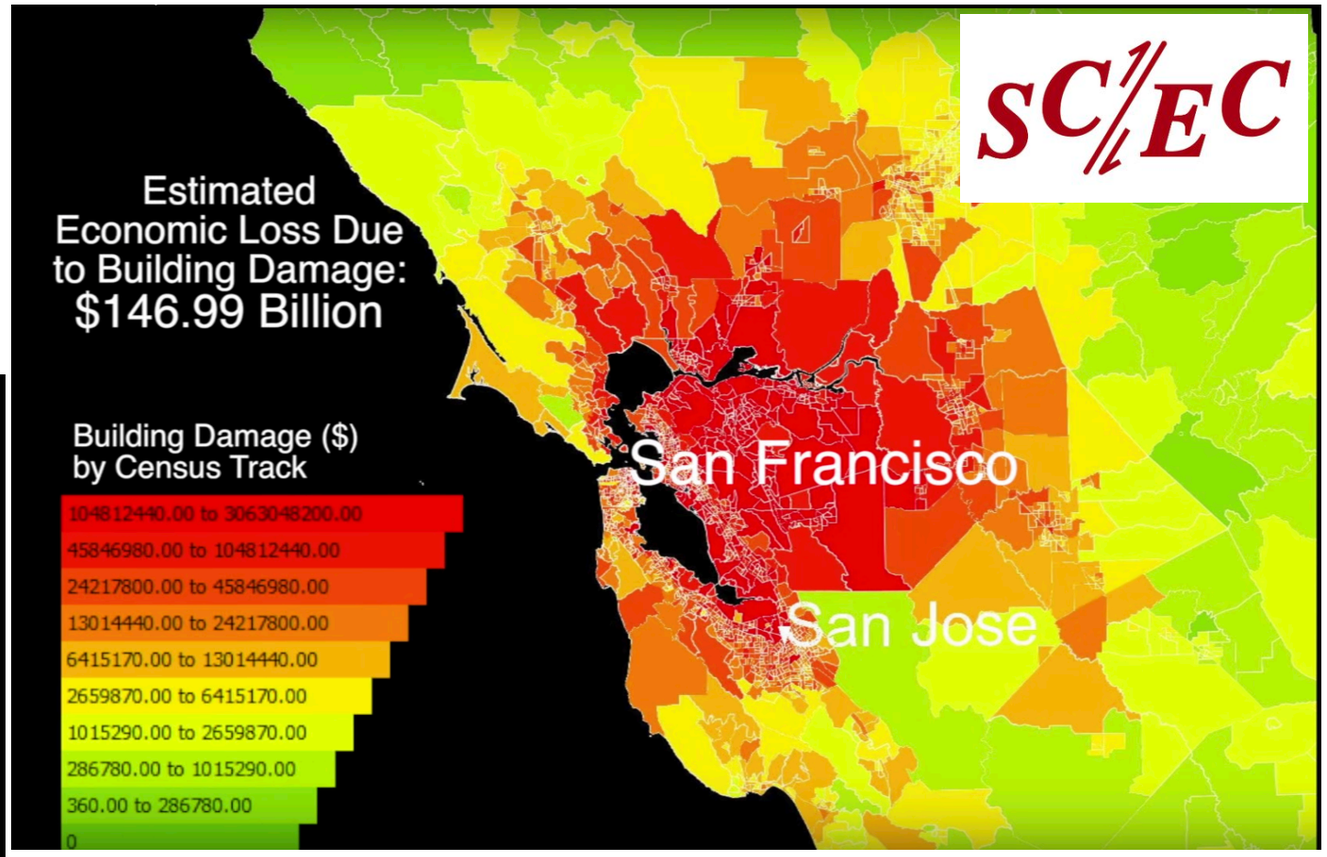


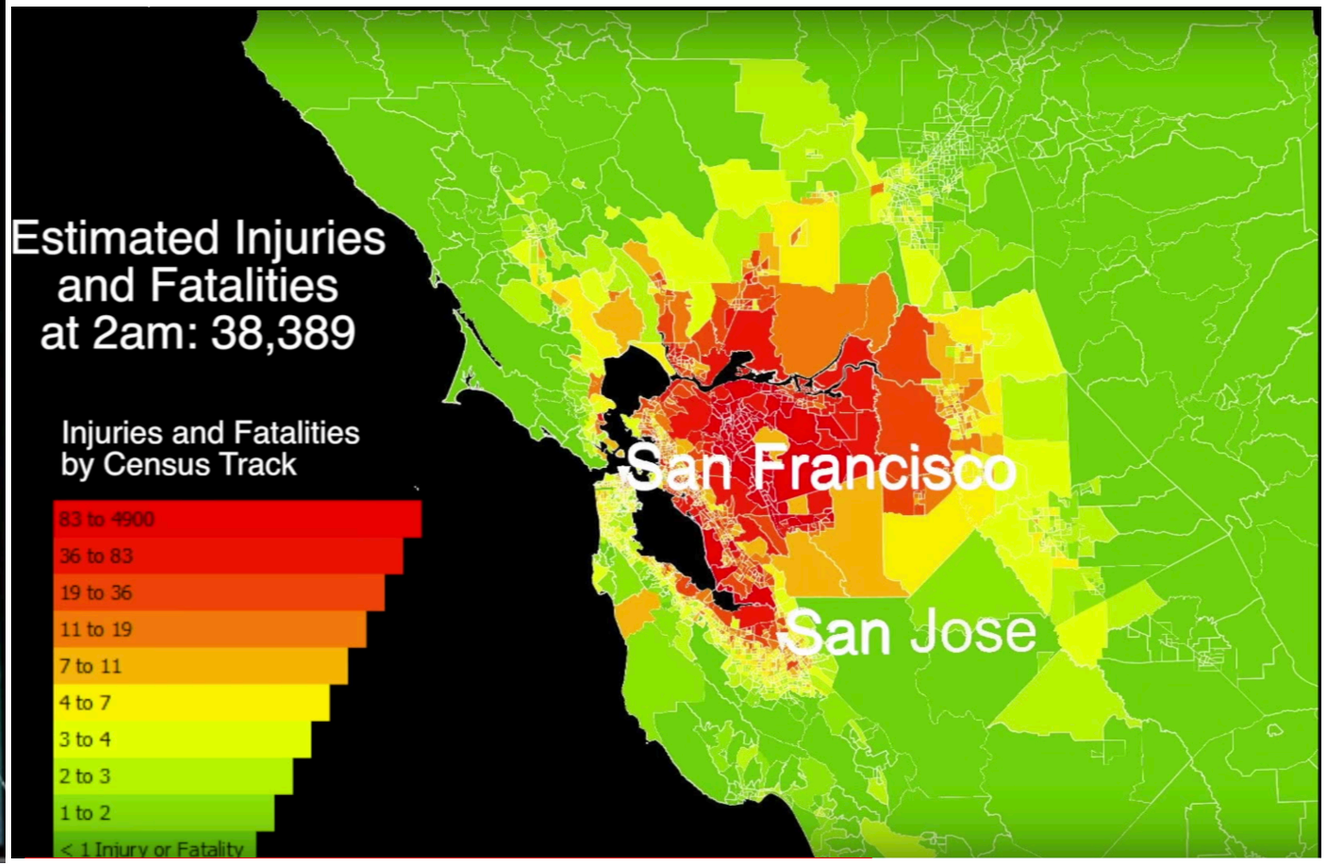
Concord fault



Estimated shaking and damage: Mw. 6.8

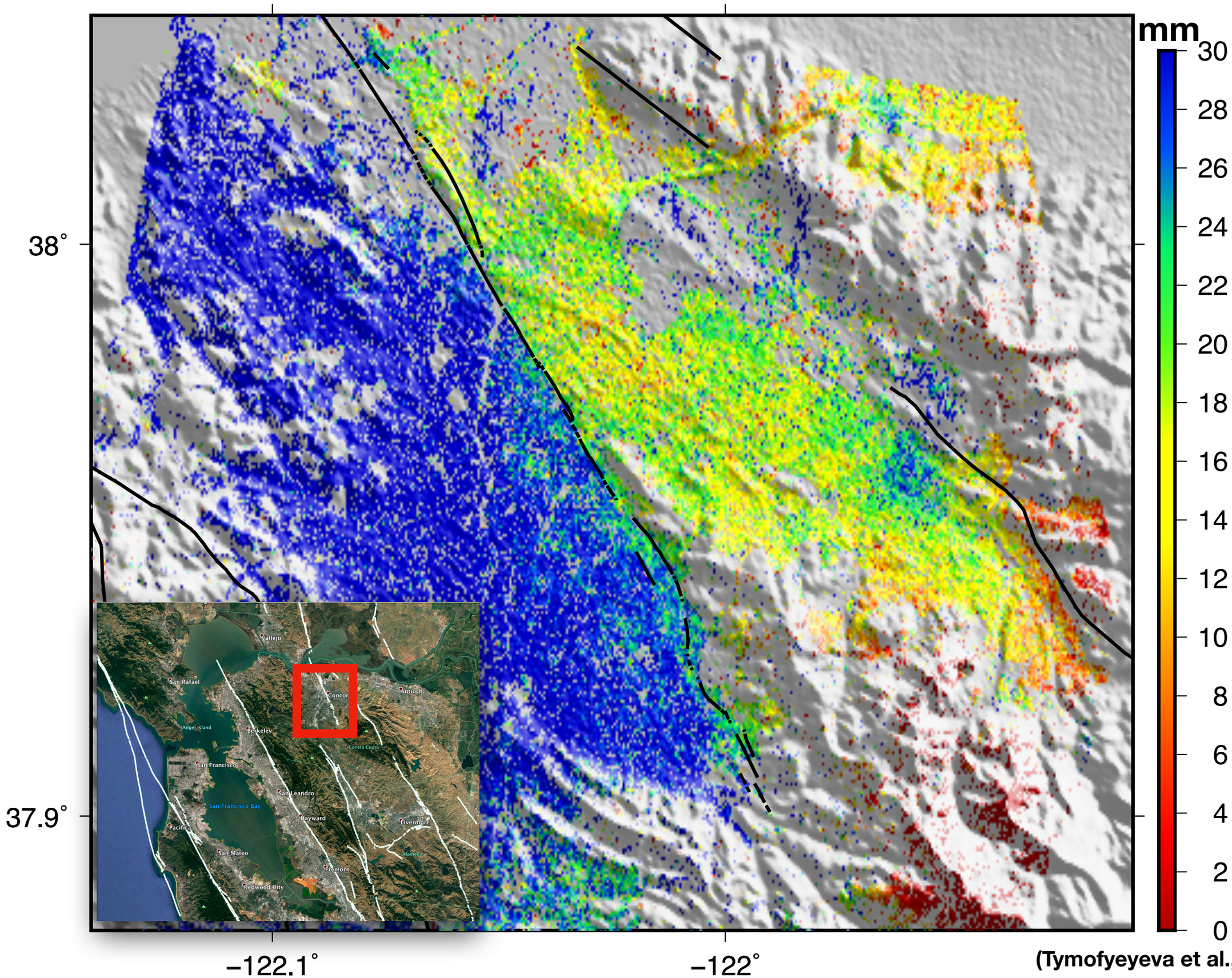






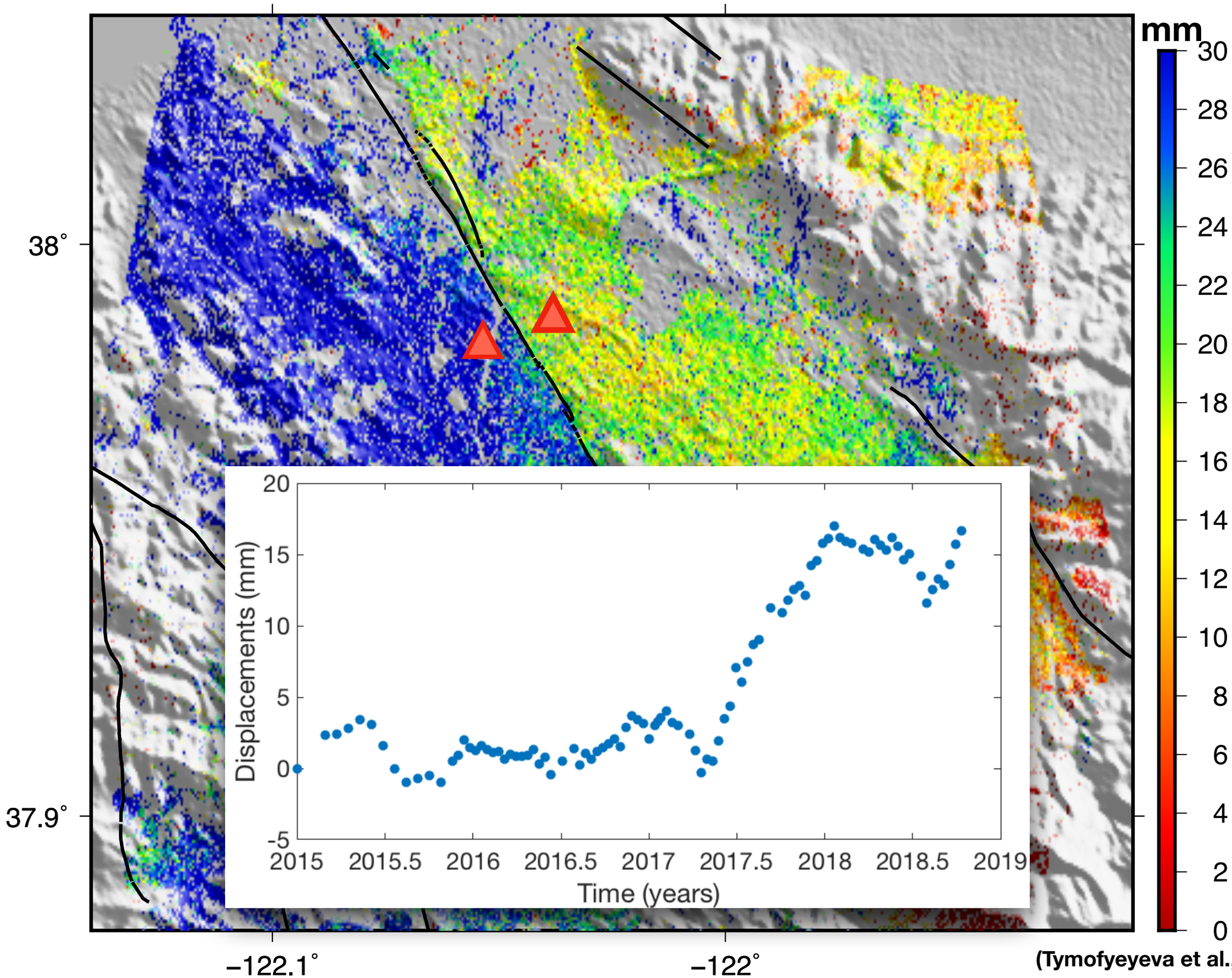
SHAKING: WEAK STRONG SEVERE

Surface displacements: 2015-2019 (Sentinel)



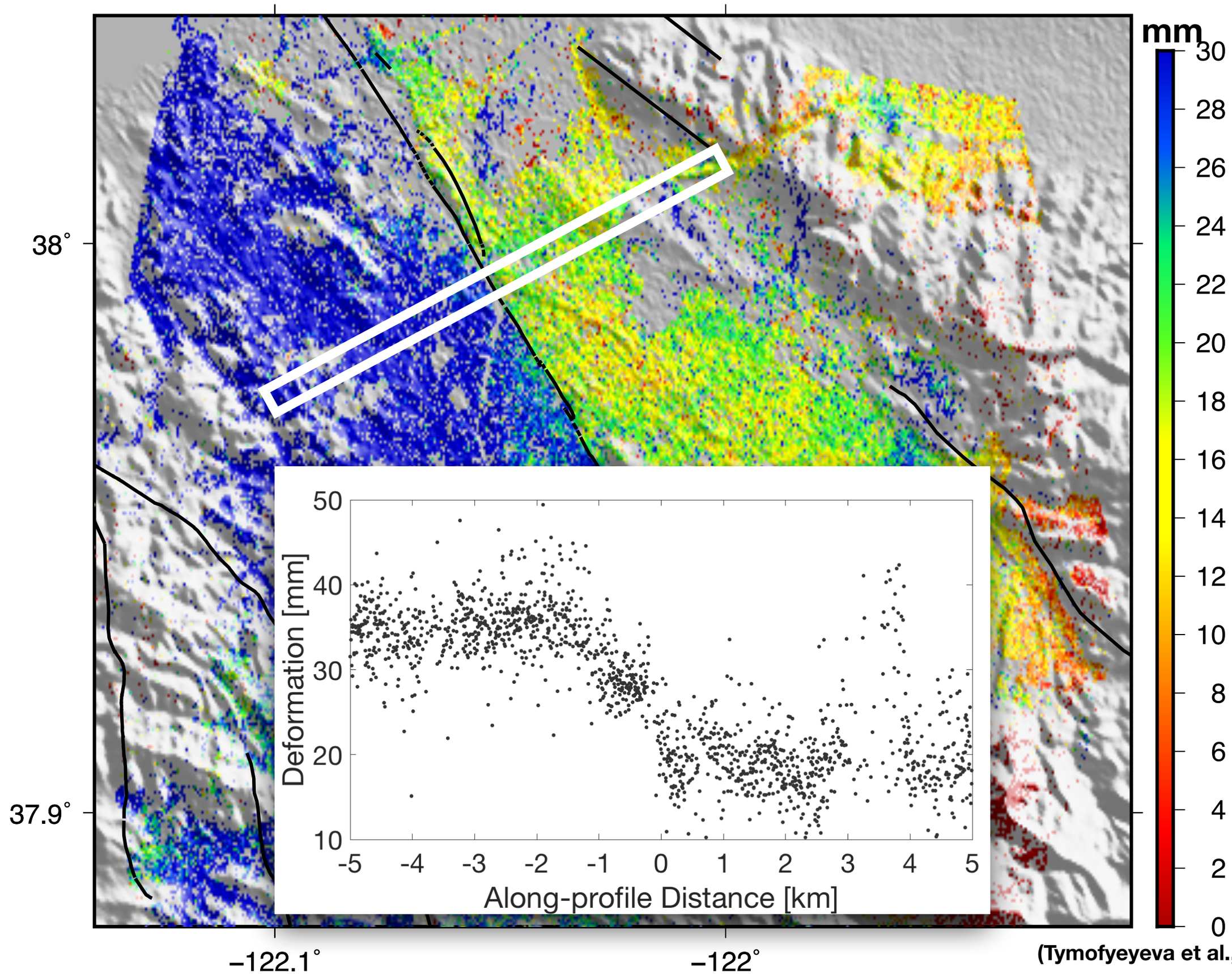
(Tymofyeyeva et al., in prep)

Surface displacements: 2015-2019 (Sentinel)



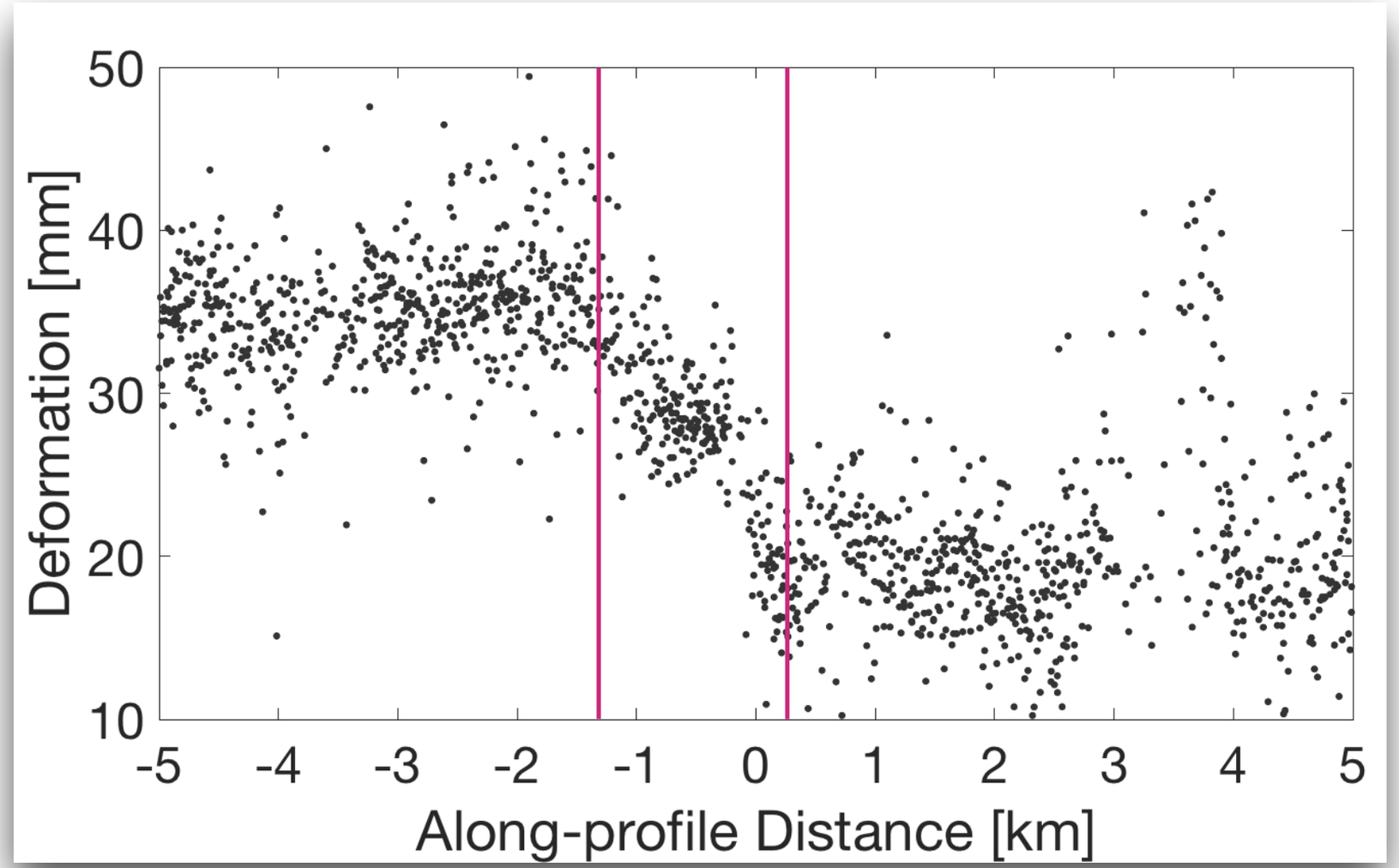
(Tymofyeyeva et al., in prep)

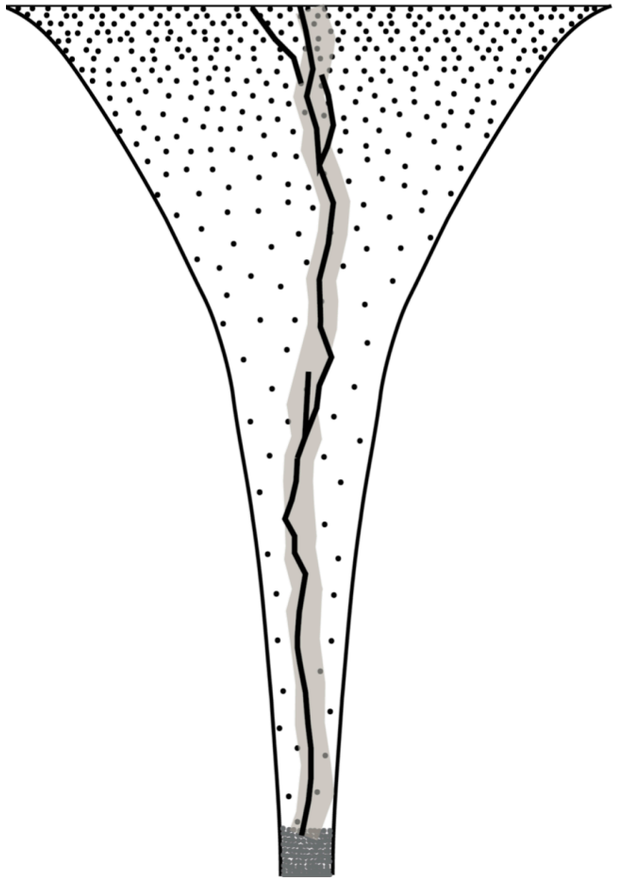
Surface displacements: 2015-2018 (Sentinel)



(Tymofyeyeva et al., in prep)

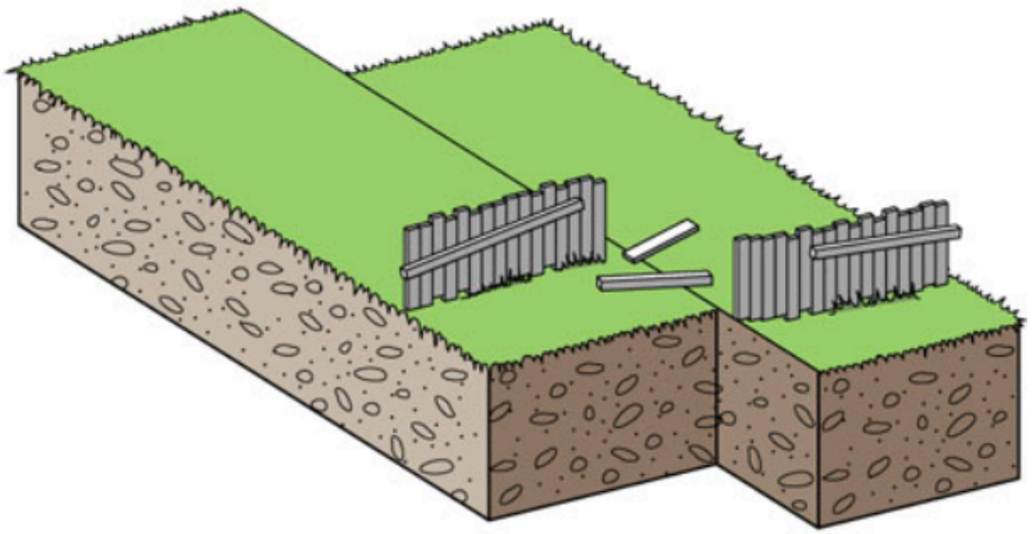
How wide is the fault?





“Flower” structure?

Infinitely thin crack?



Conclusions

- Modern satellite missions provide data sets that are unprecedented in their spatial and temporal coverage.

- Frequent InSAR data acquisitions make it possible to resolve motions of the Earth's crust on the order of a few millimeters per year, allowing for the study of time-dependent processes that drive deformation on tectonically active faults.

- Quantifying strain accumulation across active fault boundaries provides the opportunity to discover and understand previously unidentified structures.

- Observations of surface displacements at the high spatial and temporal resolution provided by modern InSAR missions allow for a re-evaluation and refinement of the assumptions used in the estimation of seismic hazard in tectonically active areas.

“Earthquake safety tip 1: To minimize loss and damage in a quake, try not to own things.”

–Wei, 2011. Chapter 1.

(For real earthquake safety tips, visit http://www.earthquakecountry.org/sevensteps/)

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