Investigation of the influence of laterally varying lithospheric properties on asymmetric strain accumulation across strike-slip faults

by Wen-Jeng Huang[1], Kaj M. Johnson[2],

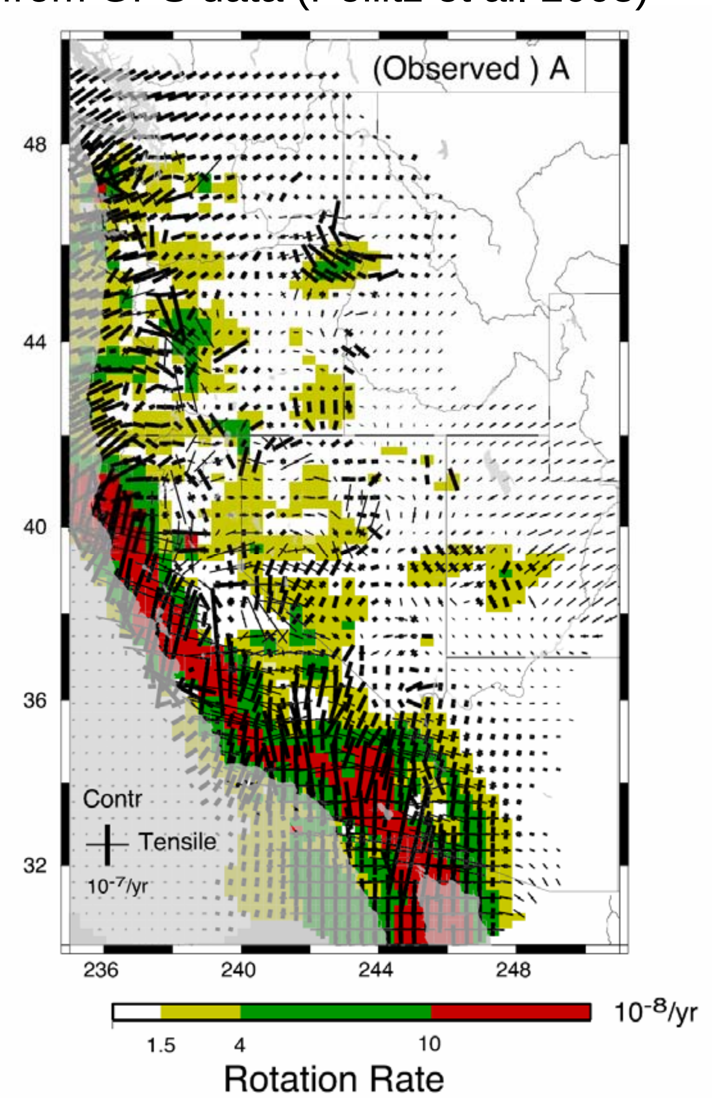
1.Academia Sinica 2.Indiana University

Presenter: Wen-Jeng Huang

DEC. 2009
AGU

The Problem

Western US Strain Rates Inferred from GPS data (Pollitz et al. 2008)

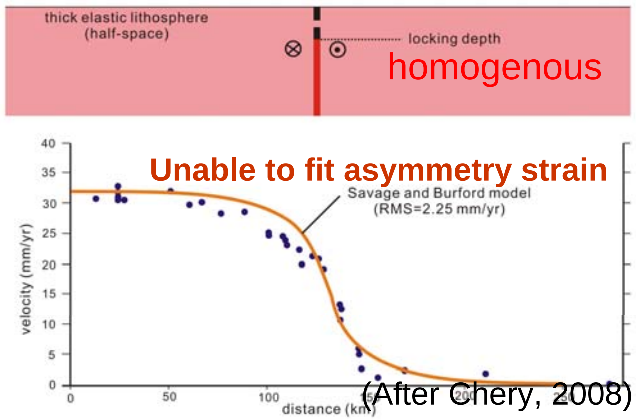


Use gradients in velocity field to identify where active faults are locked and accumulating stress.

Gradients in velocity field can be attributed to:

1. Elastic distortion around locked faults
2. Lateral variations in crustal rigidity (thickness/stiffness)

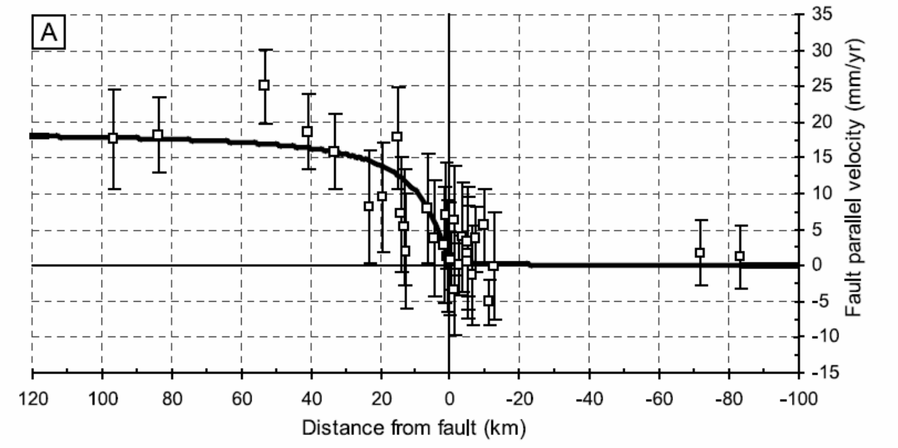
Can we use geodetic data to infer lateral variation in rigidity ?



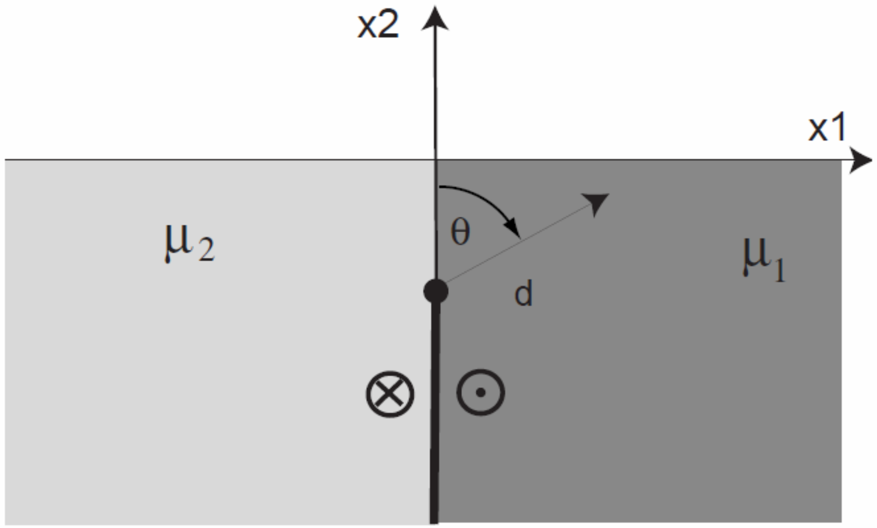
(After Chery, 2008)

Inferred Lateral Variations in Crustal Rigidity

Sumatra Fault



Idealized bimateral fault interface



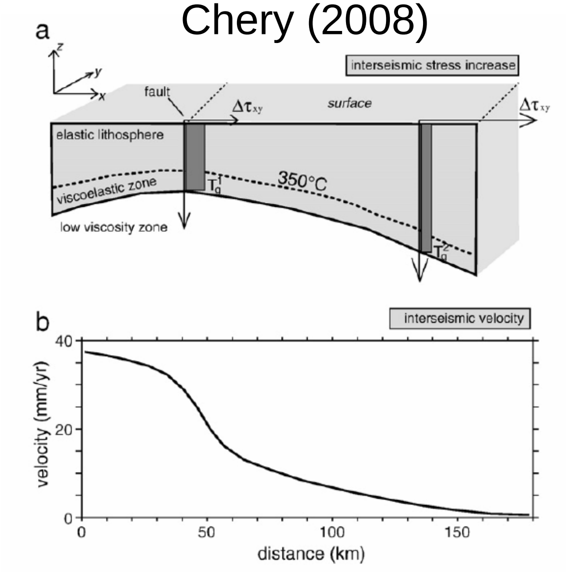
Elastic Half-Space Models

e.g., Le Pichon (2005)

Inferred rigidity ratio (μ_1/μ_2): 30

Inferred Lateral Variations in Crustal Rigidity

Chery (2008)



Jolivet et al. (2008)

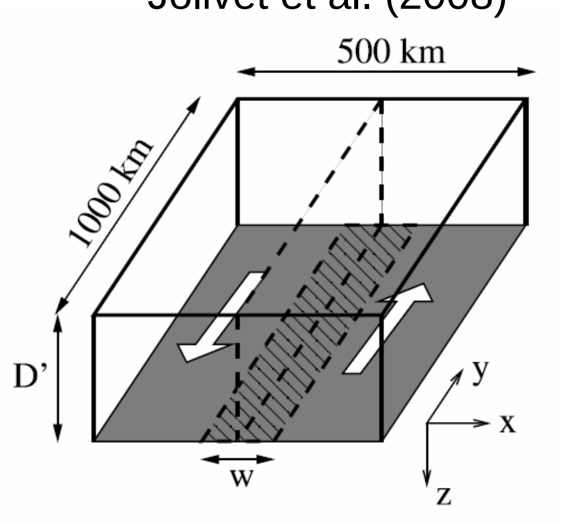


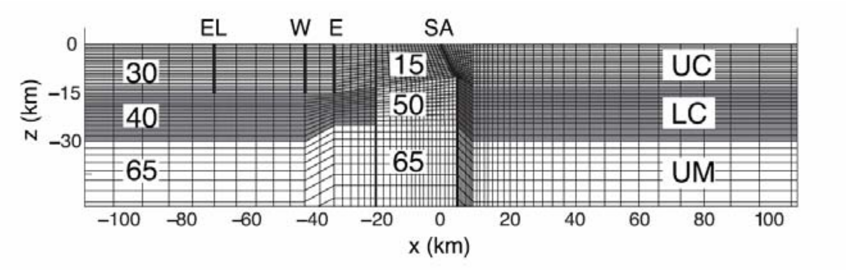
Plate Models

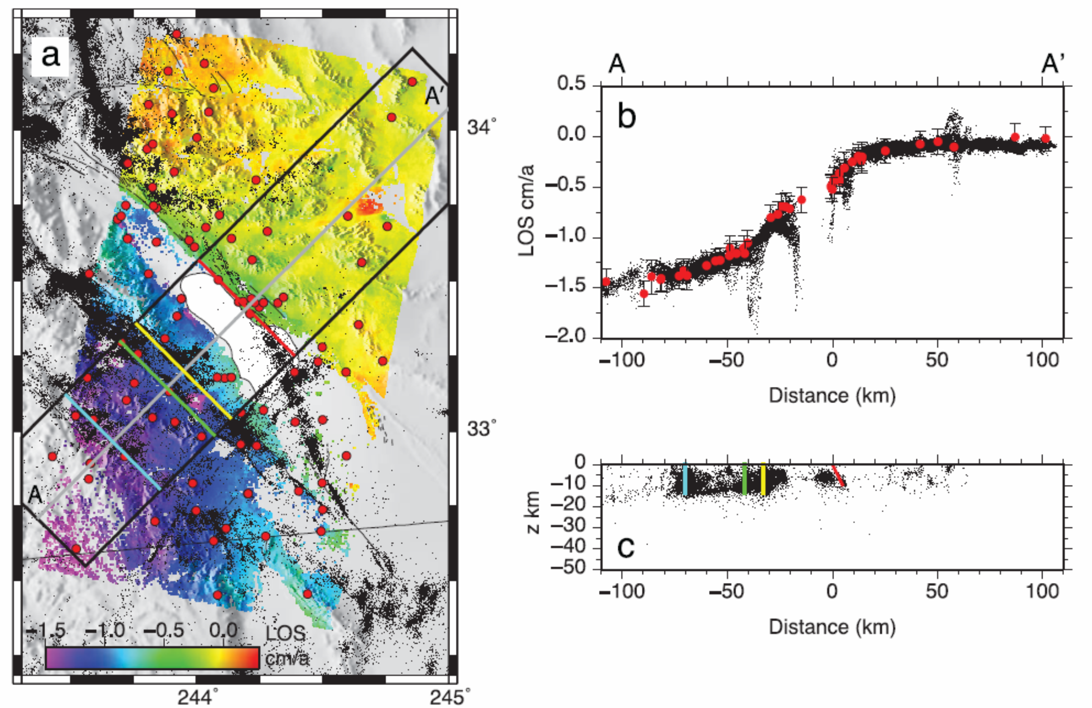
e.g., Chery (2008), Jolivet et al. (2008)

Flow underneath plates is not considered.

Inferred Lateral Variations in Crustal Rigidity

Lundgren et al. (2009)





Finite Element Models

e.g., Lundgren et al (2009), Schmalze et al. (2005)

Inversions are difficult because models are computationally expensive.

Why revisit this problem?

- Elastic half-space and plate models neglect viscous flow – we show that this is important

- Finite Element models too slow to fully explore model space

Our Approach

Forward Model

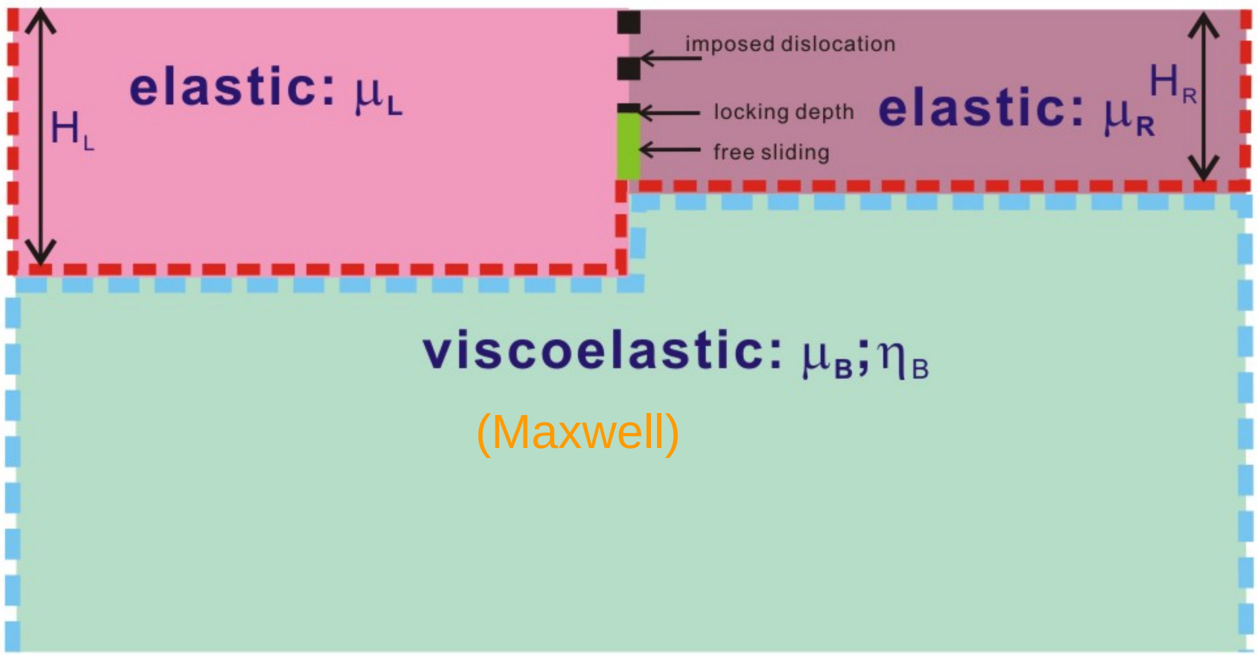
- Need fast models
- Boundary element methods for stress boundary conditions

Inverse Method

- Bayesian, probabilistic
- Want posterior probability distributions
- Monte Carlo sampling
- need to compute 100 K's of forward computations

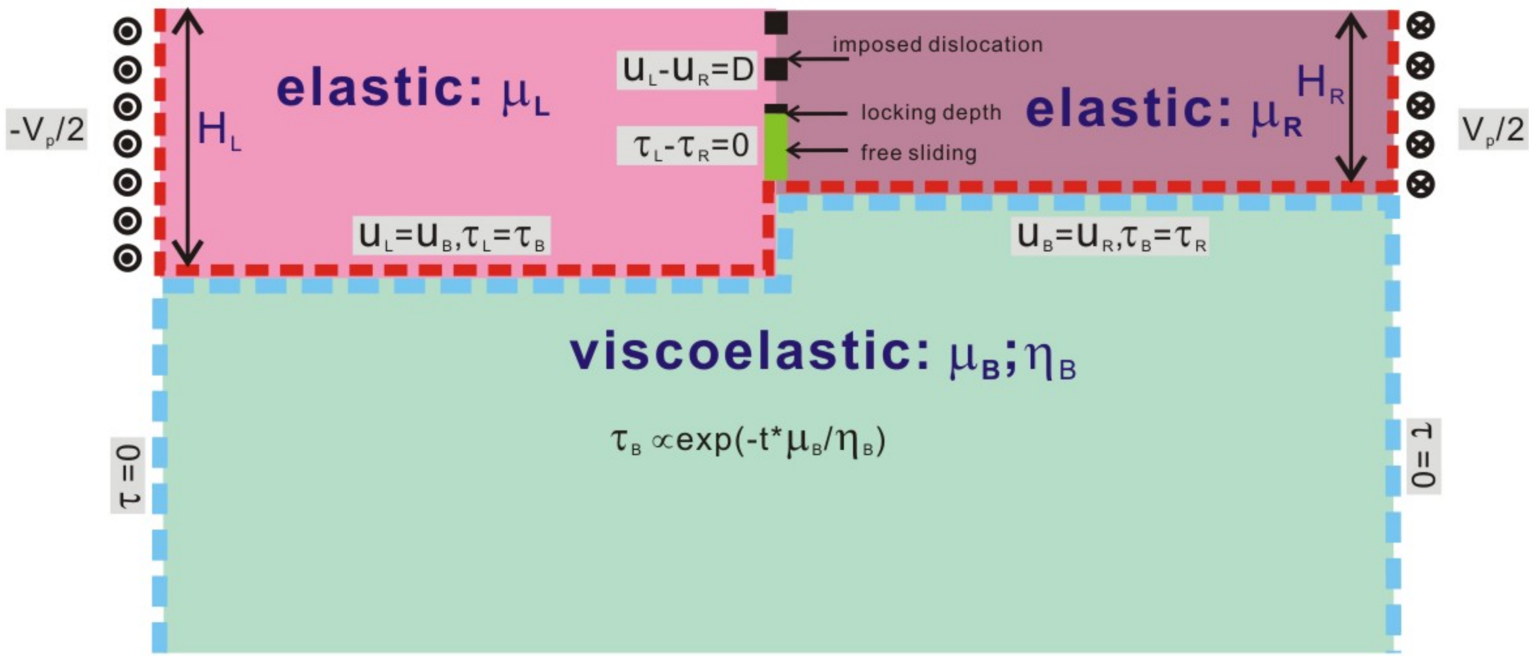
Our Model:

- Elastic layers overlying viscoelastic half-space
- Lateral variation of rigidity: e.g. stiffness and thickness
- Earthquake cycle model
- Boundary element method

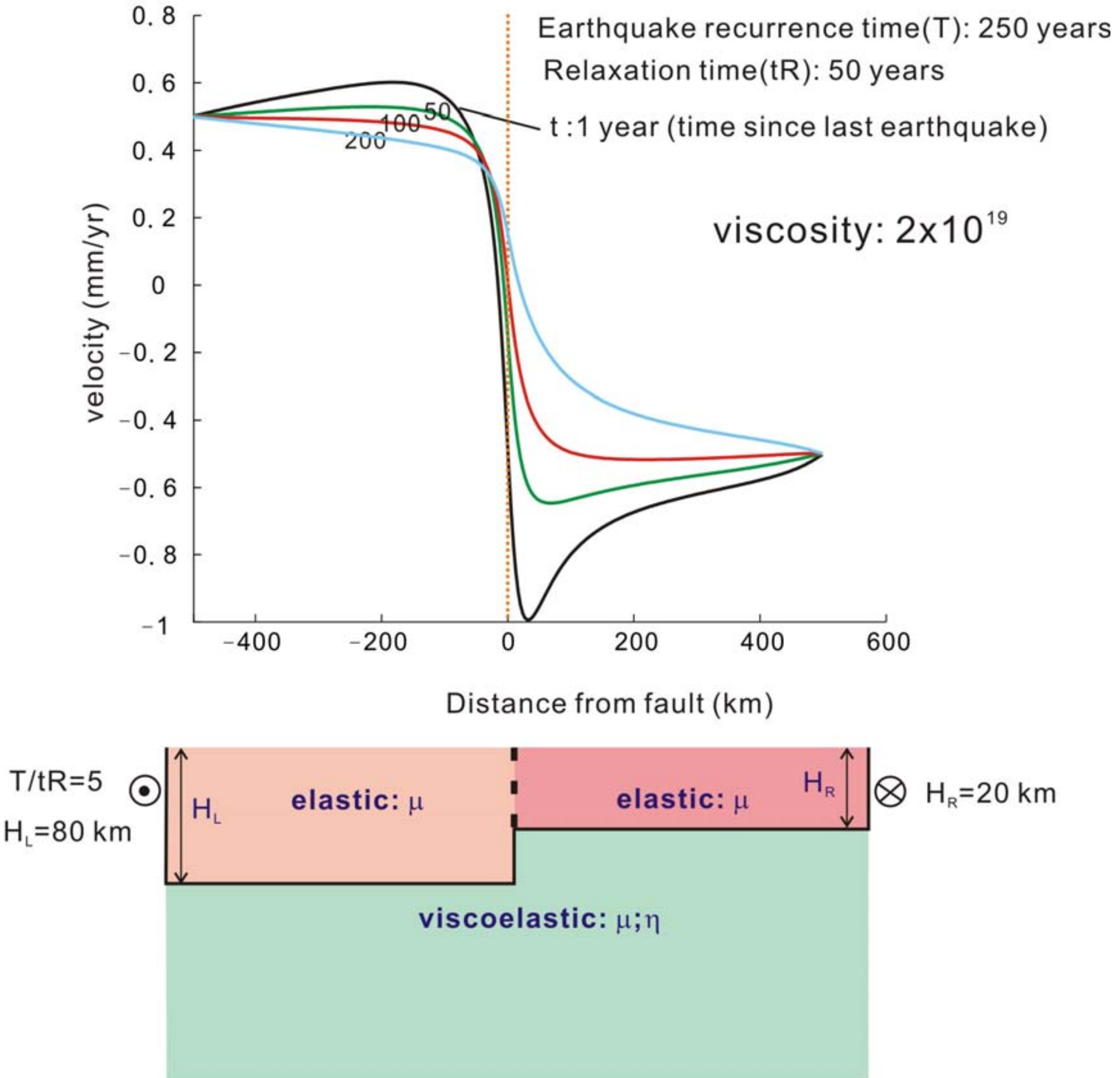


Our Model

Boundary conditions



Asymmetry of Deformation

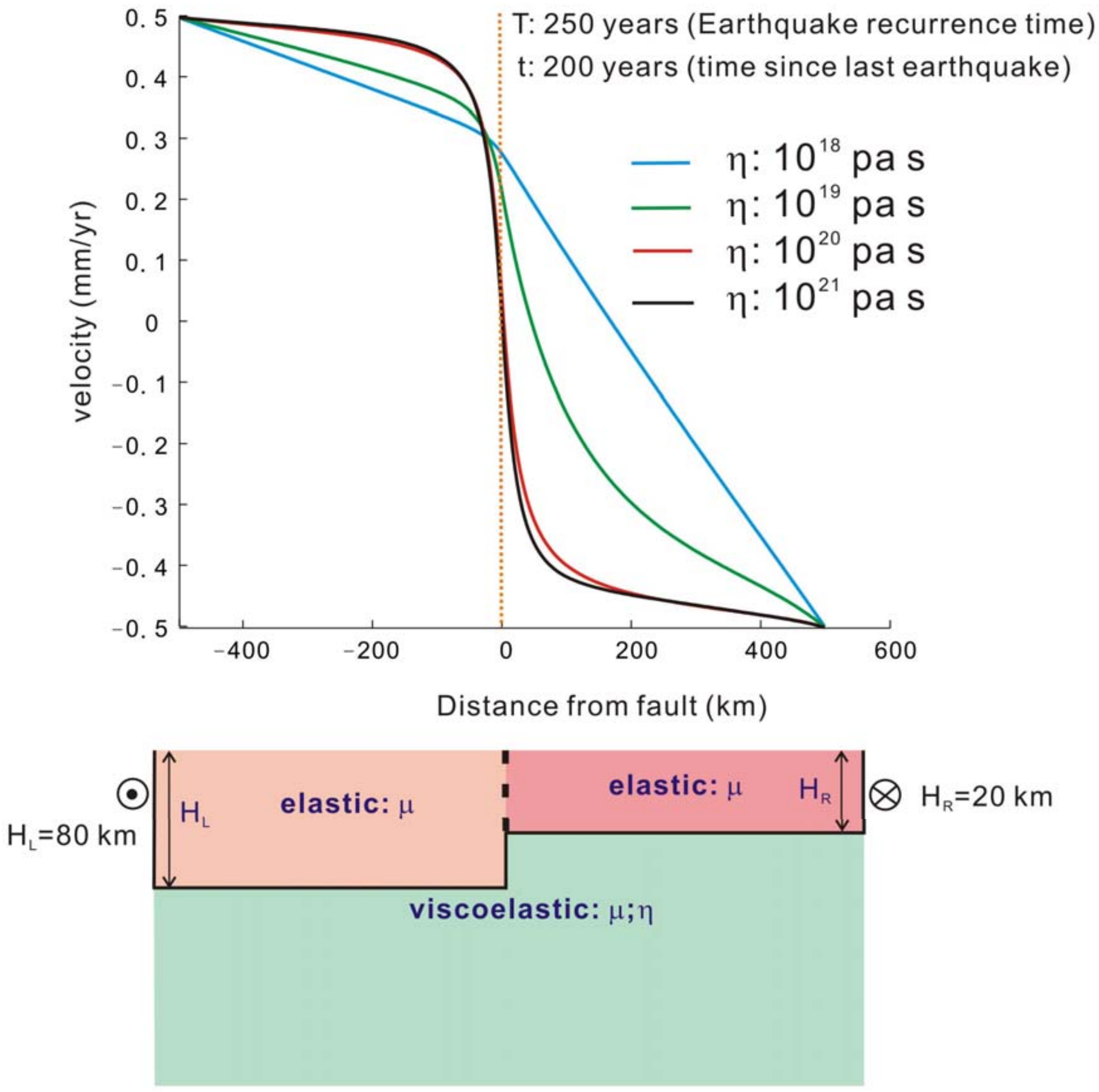


Contrast in Elastic Thickness

Asymmetry varies with the time since last earthquake (t)

Asymmetry is more pronounced at early times

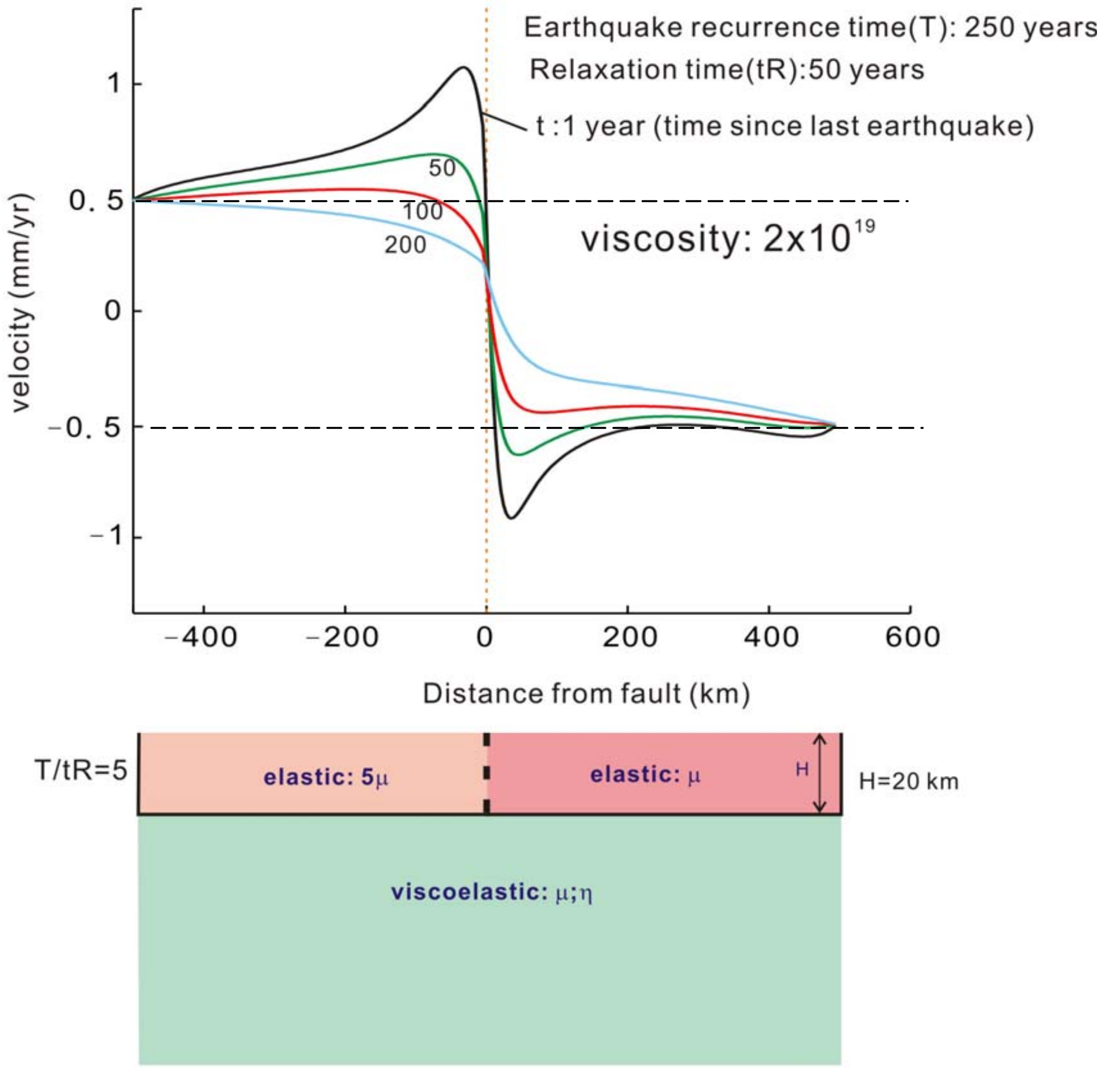
Asymmetry of Deformation



Contrast in Elastic Thickness

Asthenosphere viscosity is important:
Asymmetry is more pronounced for lower viscosities

Asymmetry of Deformation

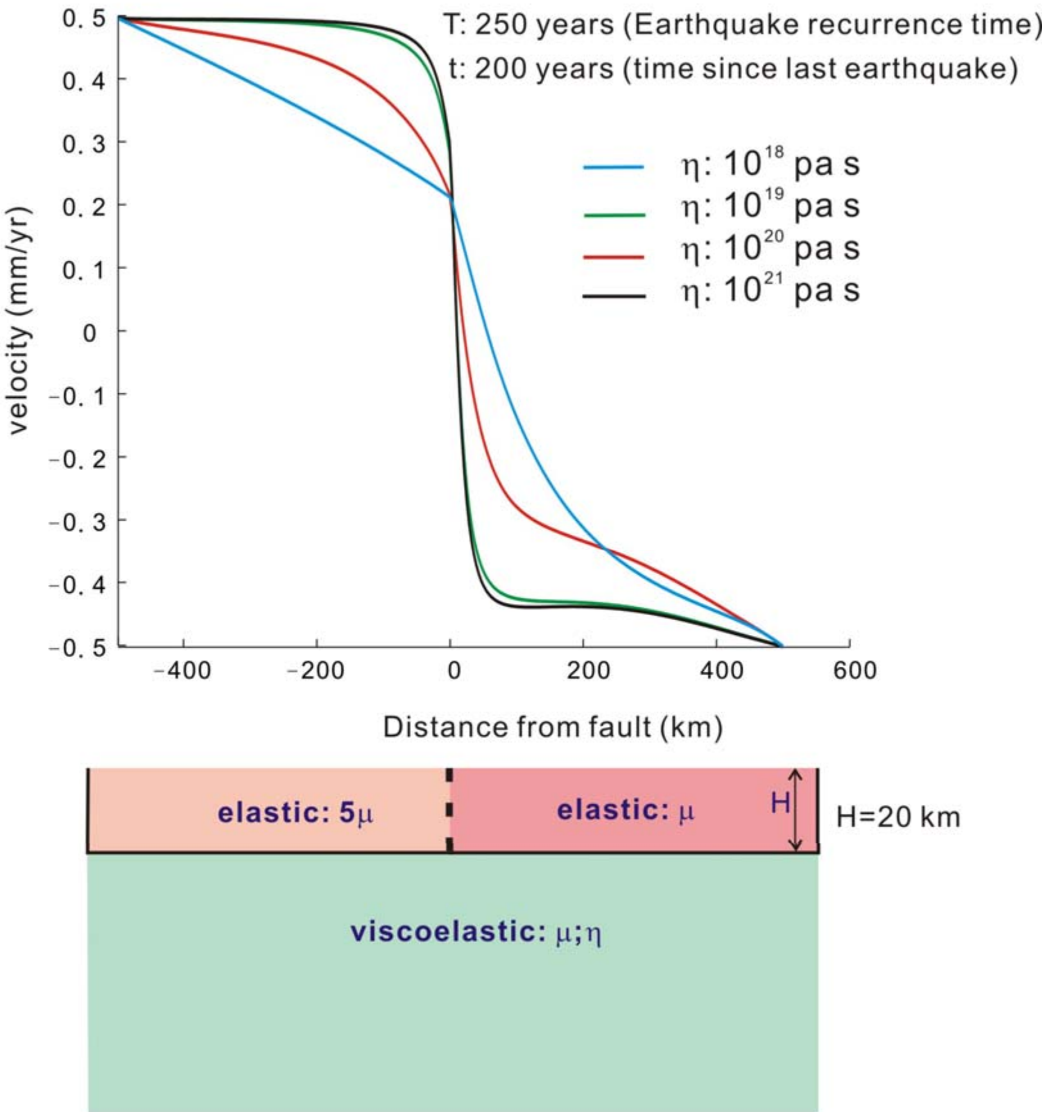


Contrast in Elastic stiffness

Asymmetry varies with the time since last earthquake (t)

Asymmetry is more pronounced at later times

Asymmetry of Deformation

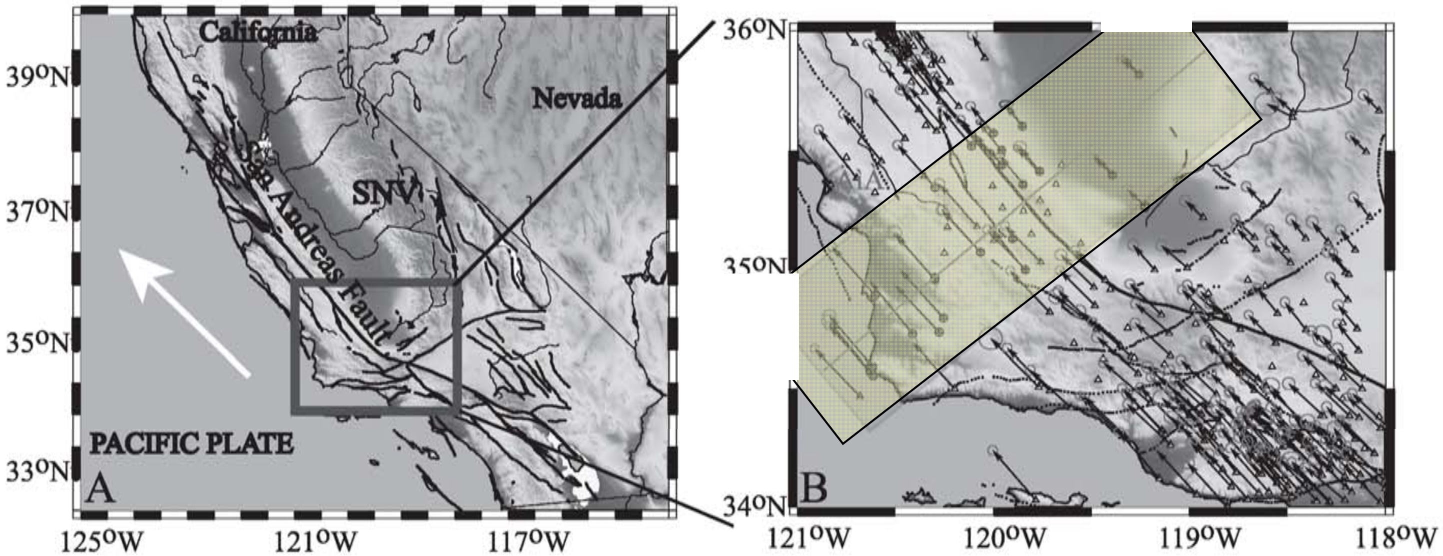


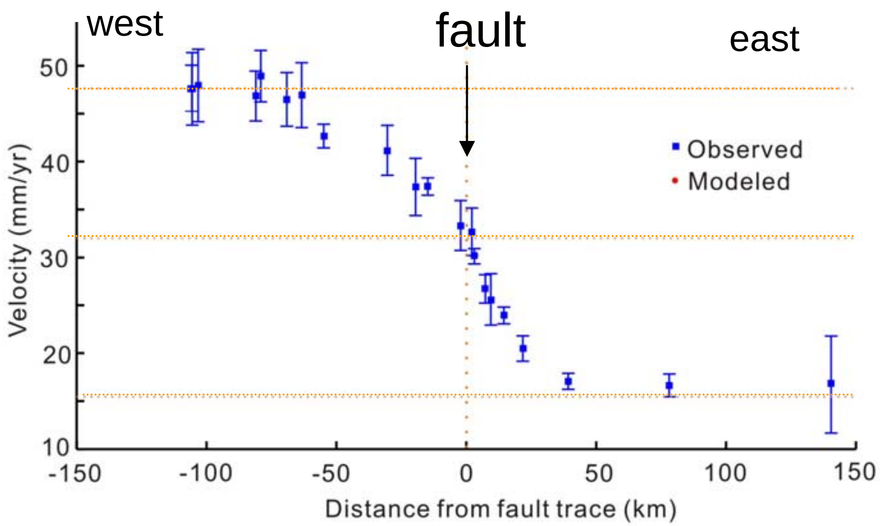
Contrast in Elastic stiffness

Asthenosphere viscosity is important:

Asymmetry is more pronounced for lower viscosities

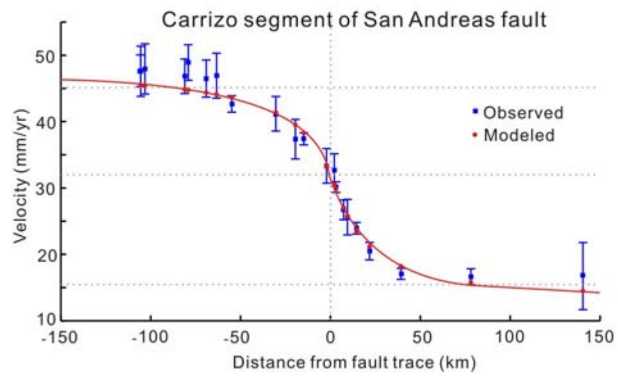
Carrizo segment of San Andreas Fault



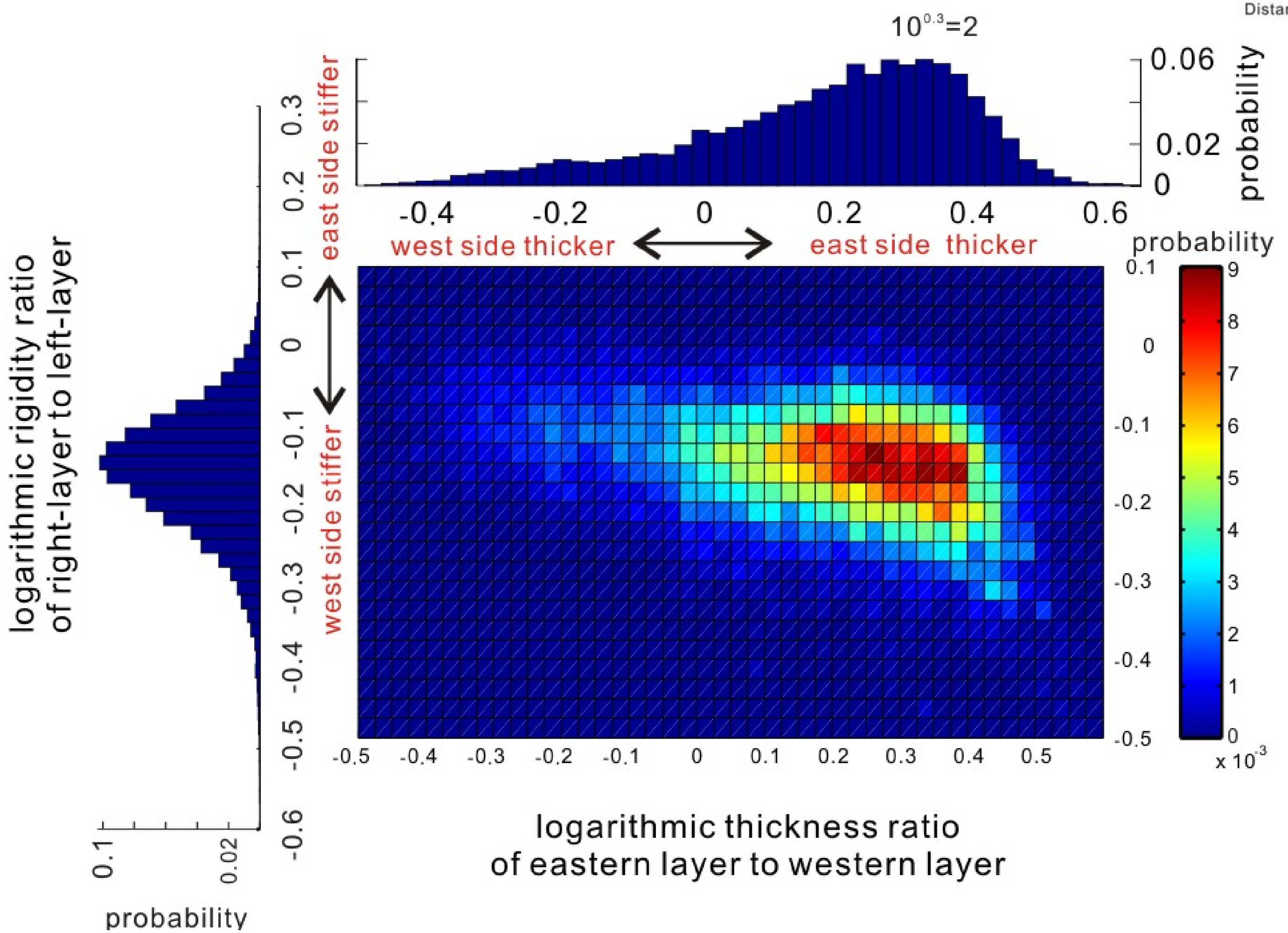


(Schmalze et al., 2006)

Results



Carrizo segment of San Andreas fault
Observed
Modeled
Velocity (mm/yr)
Distance from fault trace (km)



$10^{0.3}=2$
probability
west side thicker
east side thicker
east side stiffer
west side stiffer
logarithmic rigidity ratio of right-layer to left-layer
logarithmic thickness ratio of eastern layer to western layer
probability
$\times 10^{-3}$

Results

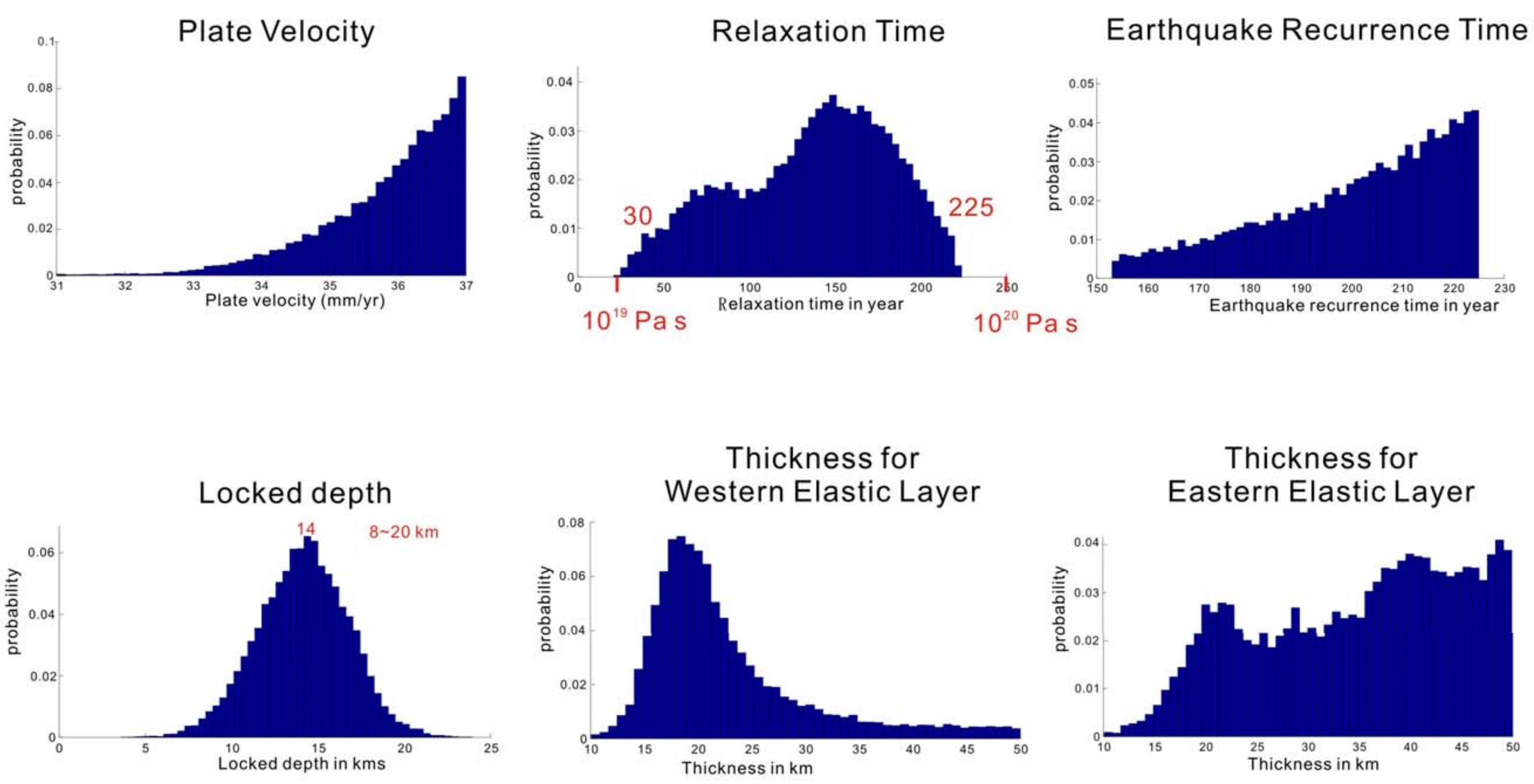
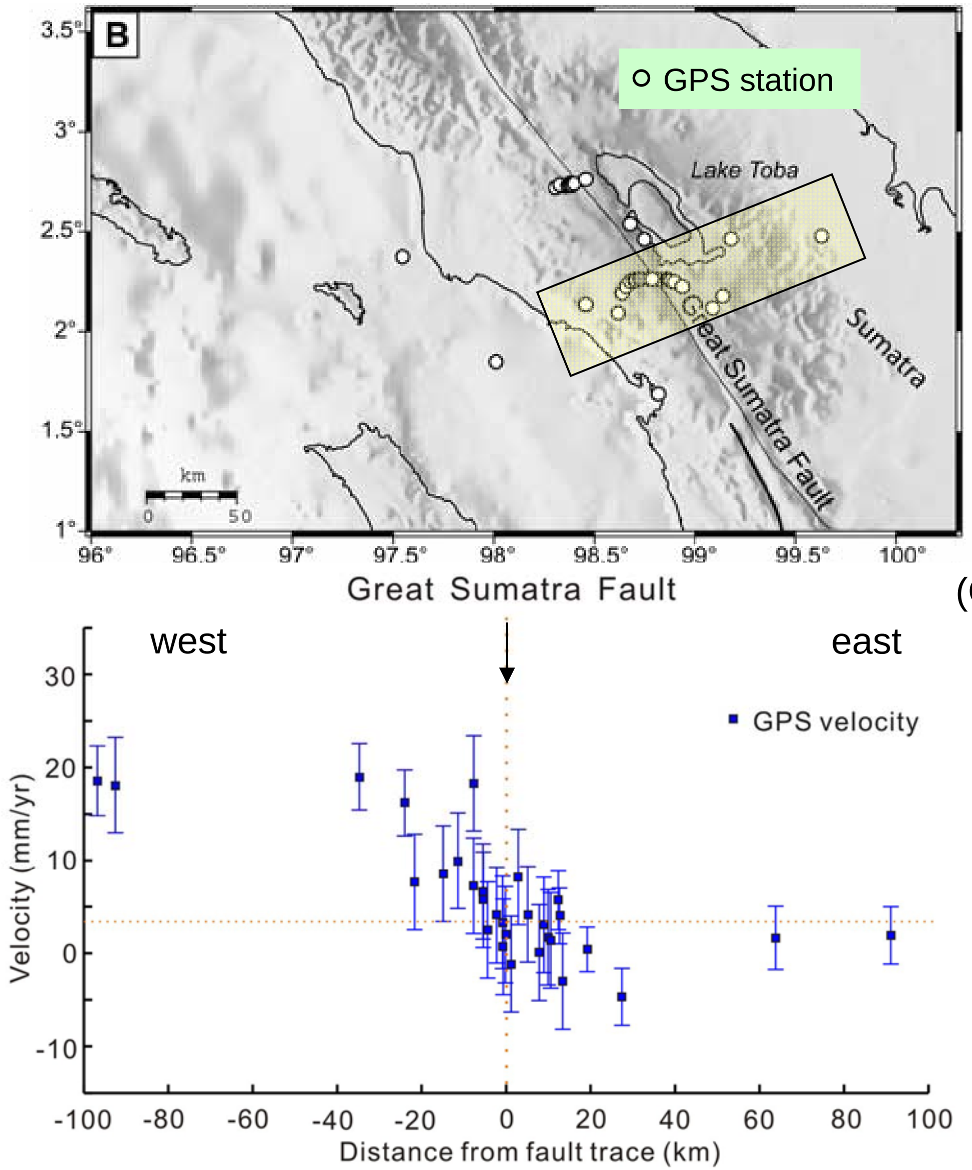


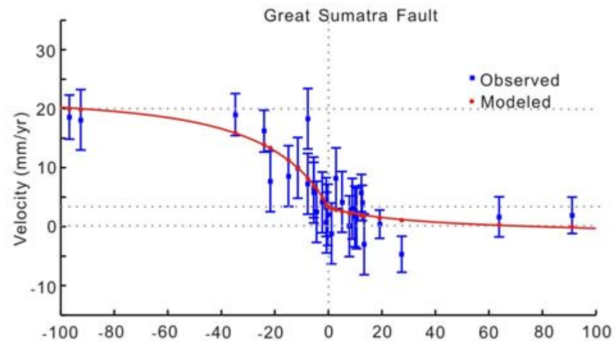
Plate Velocity
probability
Plate velocity (mm/yr)
Relaxation Time
30
225
Relaxation time in year
10^{19} Pa s
10^{20} Pa s
Earthquake Recurrence Time
Earthquake recurrence time in year
Locked depth
14
8~20 km
Locked depth in kms
Thickness for
Western Elastic Layer
Thickness in km
Thickness for
Eastern Elastic Layer
Thickness in km

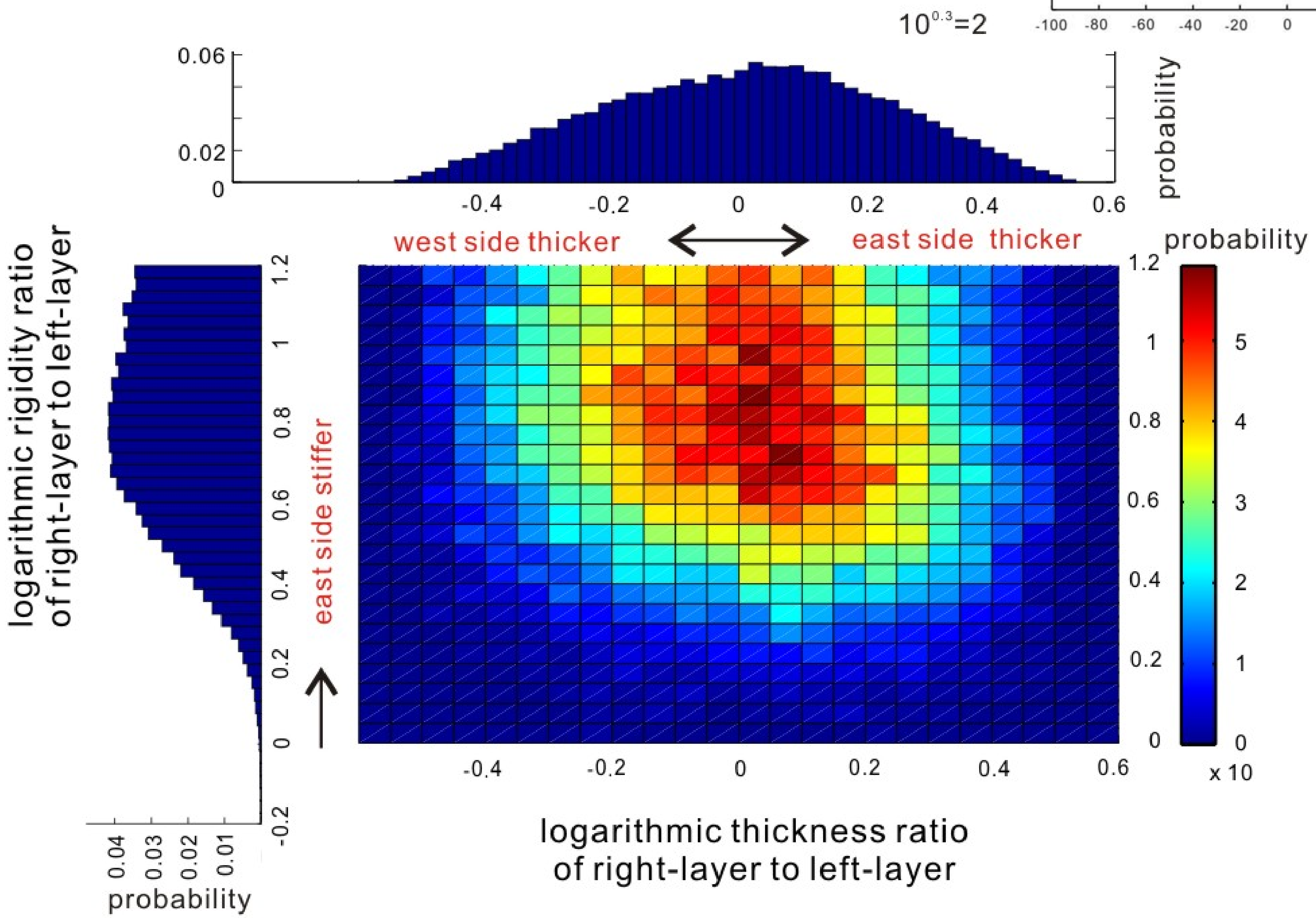
Great Sumatra Fault



(Genrich et al., 2000; Le Pichon, 2005)

Results


Great Sumatra Fault
Observed
Modeled
Velocity (mm/yr)
30
20
10
0
-10
-100 -80 -60 -40 -20 0 20 40 60 80 100


$10^{0.3}=2$
0.06
0.02
0
-0.4 -0.2 0 0.2 0.4 0.6
probability
west side thicker
east side thicker
probability
logarithmic rigidity ratio
of right-layer to left-layer
1.2 1 0.8 0.6 0.4 0.2 0 -0.2
0.04 0.03 0.02 0.01
probability
east side stiffer
5 4 3 2 1 0
x 10
logarithmic thickness ratio
of right-layer to left-layer

Results

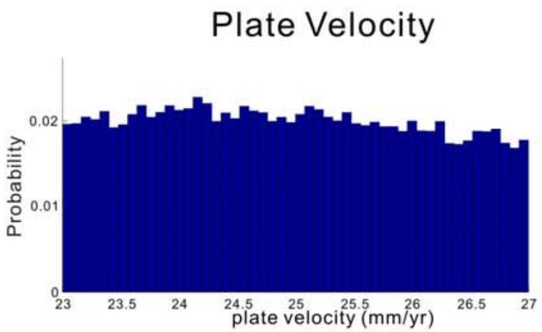
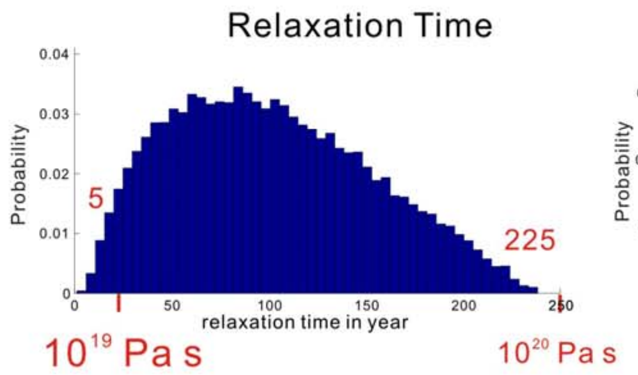
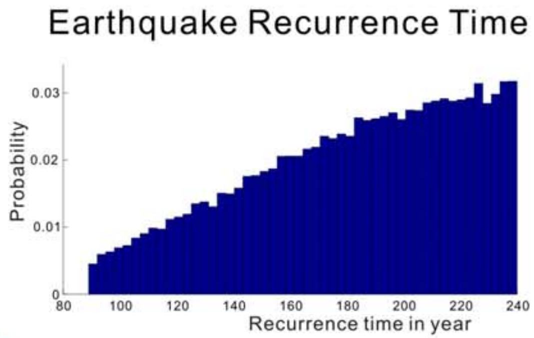
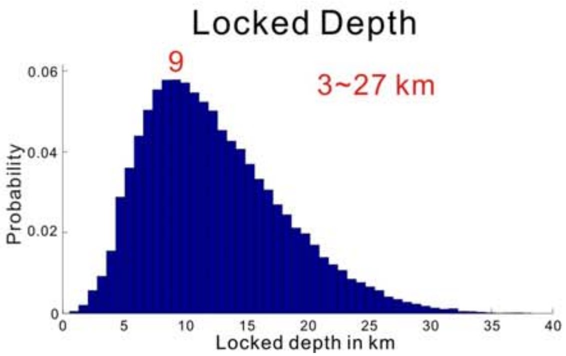
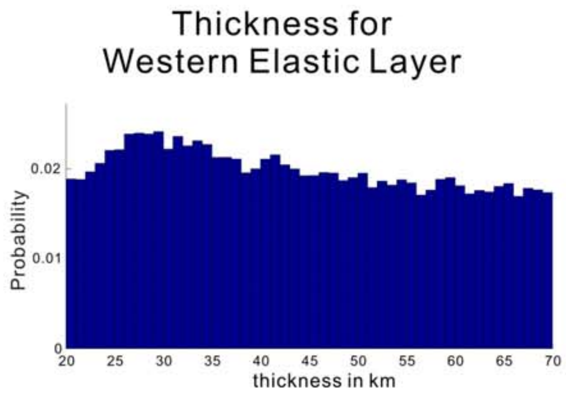


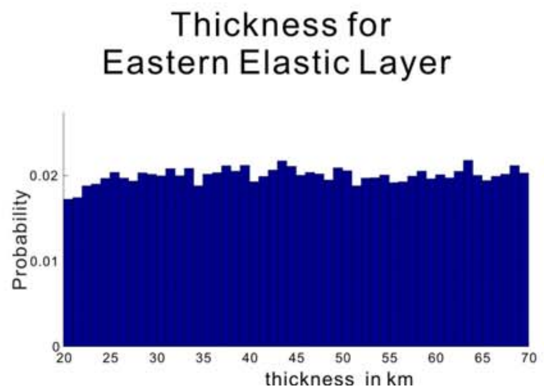
Plate Velocity
Probability
plate velocity (mm/yr)


Relaxation Time
Probability
5
225
relaxation time in year
10^{19} Pa s
10^{20} Pa s


Earthquake Recurrence Time
Probability
Recurrence time in year


Locked Depth
9
3~27 km
Probability
Locked depth in km


Thickness for
Western Elastic Layer
Probability
thickness in km


Thickness for
Eastern Elastic Layer
Probability
thickness in km

Conclusions

- The asymmetry of strain patterns attributed to the elastic thickness or stiffness contrast becomes more pronounced for lower viscosities and varies with the time since last earthquake.
- For Carrizo segment of the San Andreas fault, the inversion favors a thicker layer on east side (2 times) but stiffer layer on west side (1.4 times); however, uniform thickness and stiffness cannot be ruled out.
- For Sumatra fault, the inversion result shows eastern elastic layer must be stiffer than western one but there is no resolved a contrast in elastic thickness.