Strain accumulation across strike-slip faults: Investigation of the influence of laterally varying lithospheric properties

NCU in Taiwan

Wen-Jeng Huang and Kaj M. Johnson

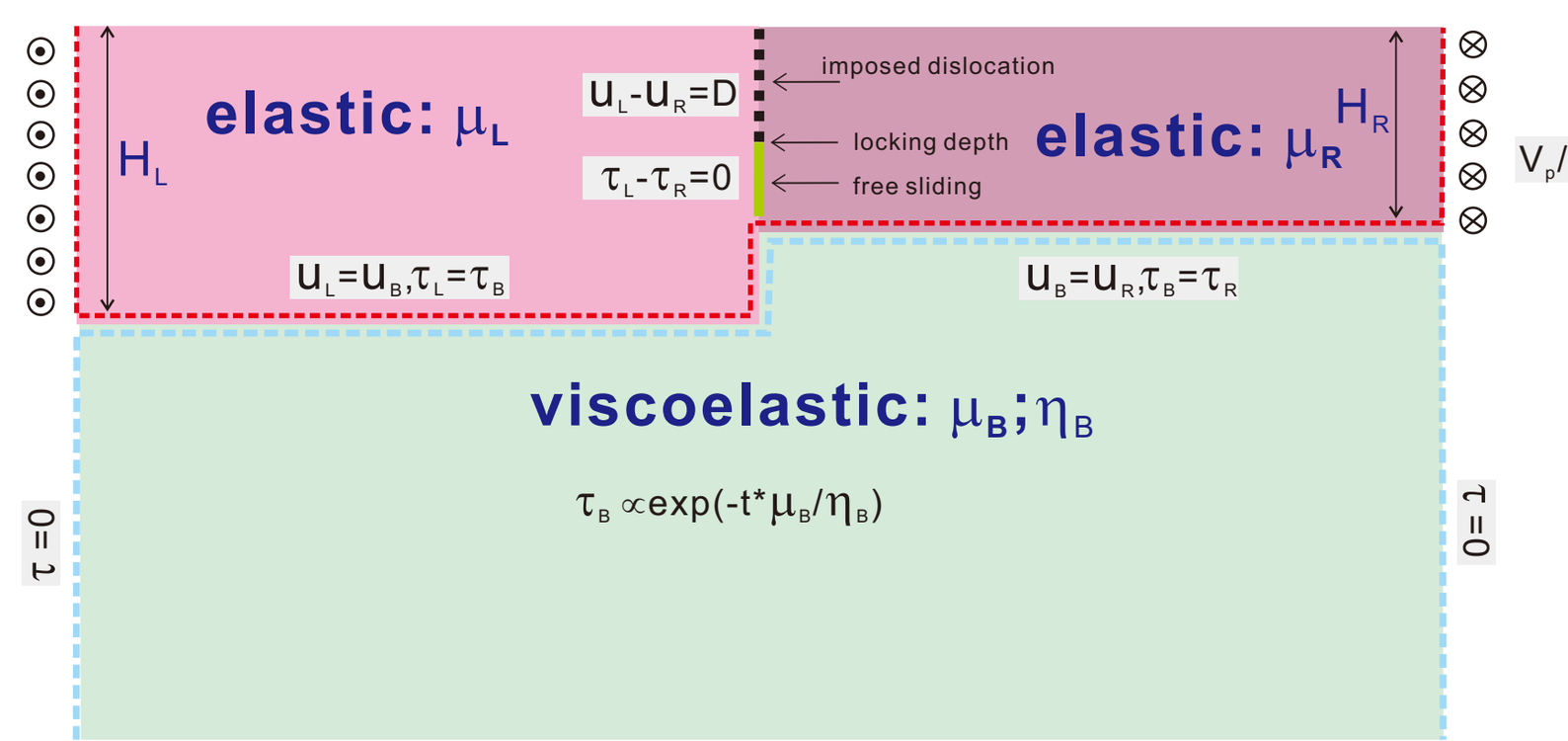
[1]National Central University in Taiwan (contact info: huang22@ncu.edu.tw),[2]Indiana University in USA (kajjohns@indiana.edu)

INDIANA UNIVERSITY

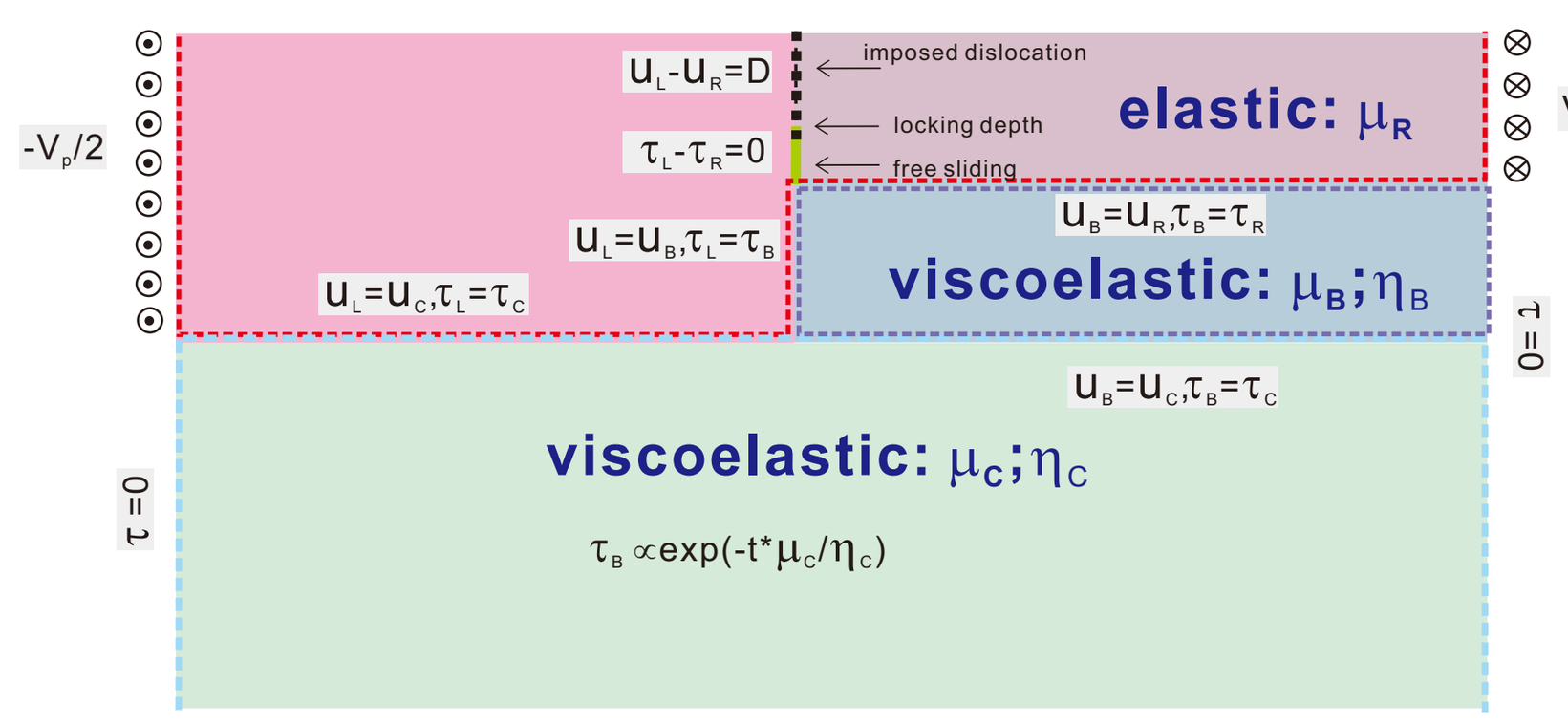
Introduction:

We use **boundary element methods** to develop **earthquake cycle models** consisting of faulting in an elastic plate with possibly **different thickness** and **rigidity** on either side of the fault overlying a viscoelastic substrate. We show that **isolate plate models** that neglect the coupling of the plate to the underlying substrate might **significantly overpredict the asymmetry** in deformation across the fault. We also show **a low-viscosity channel** that exists **within lower crust** could **significantly contribute to the asymmetry**.

model I

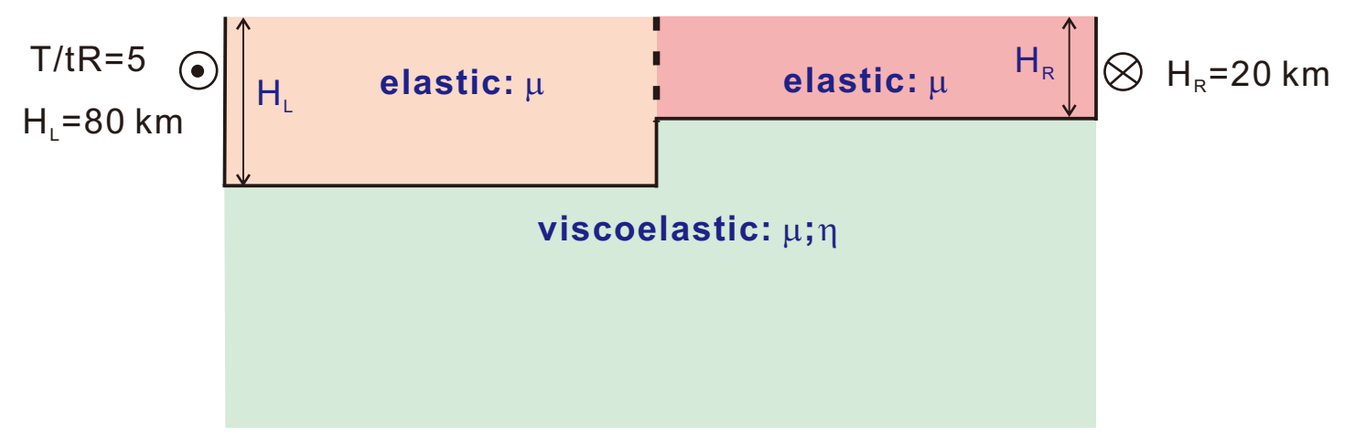


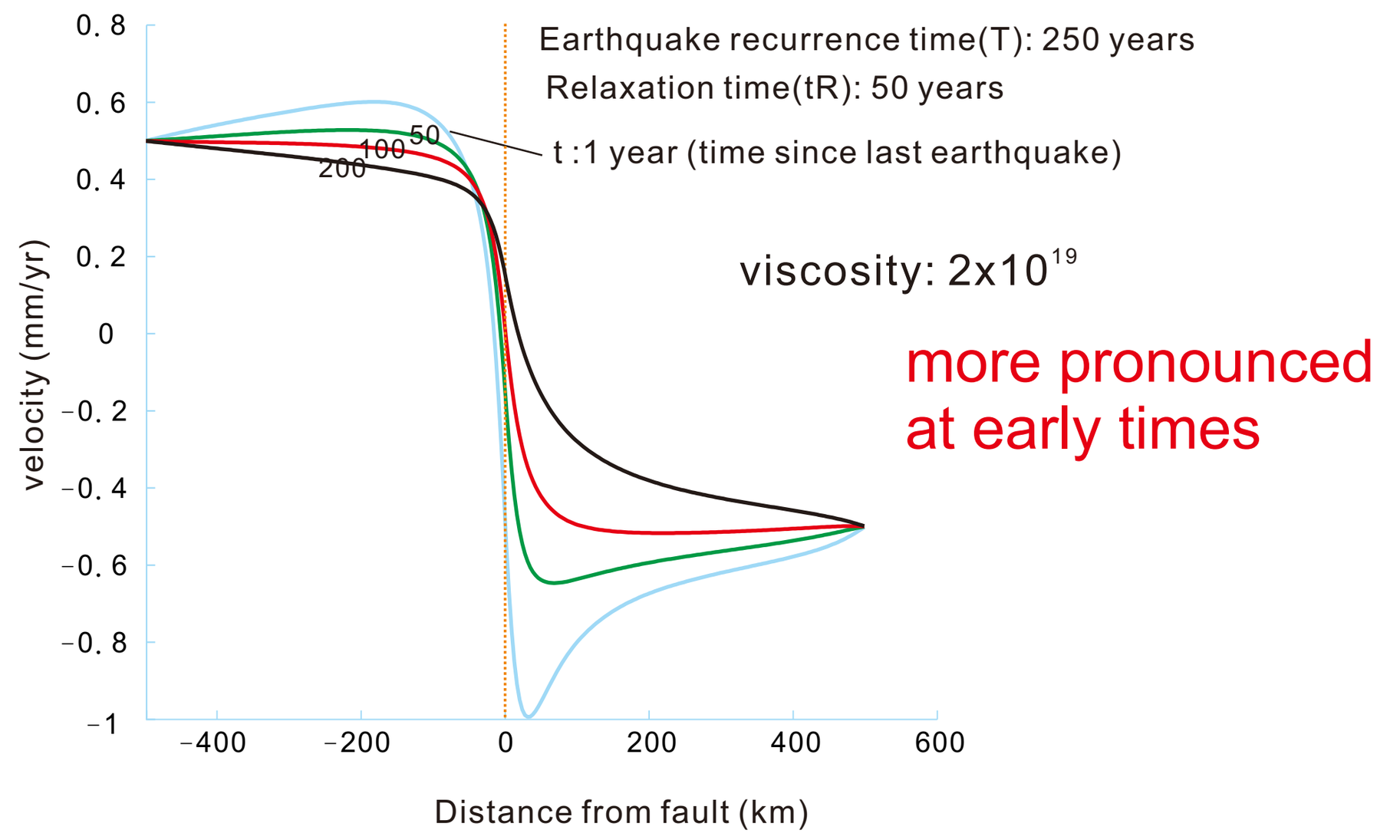
model II

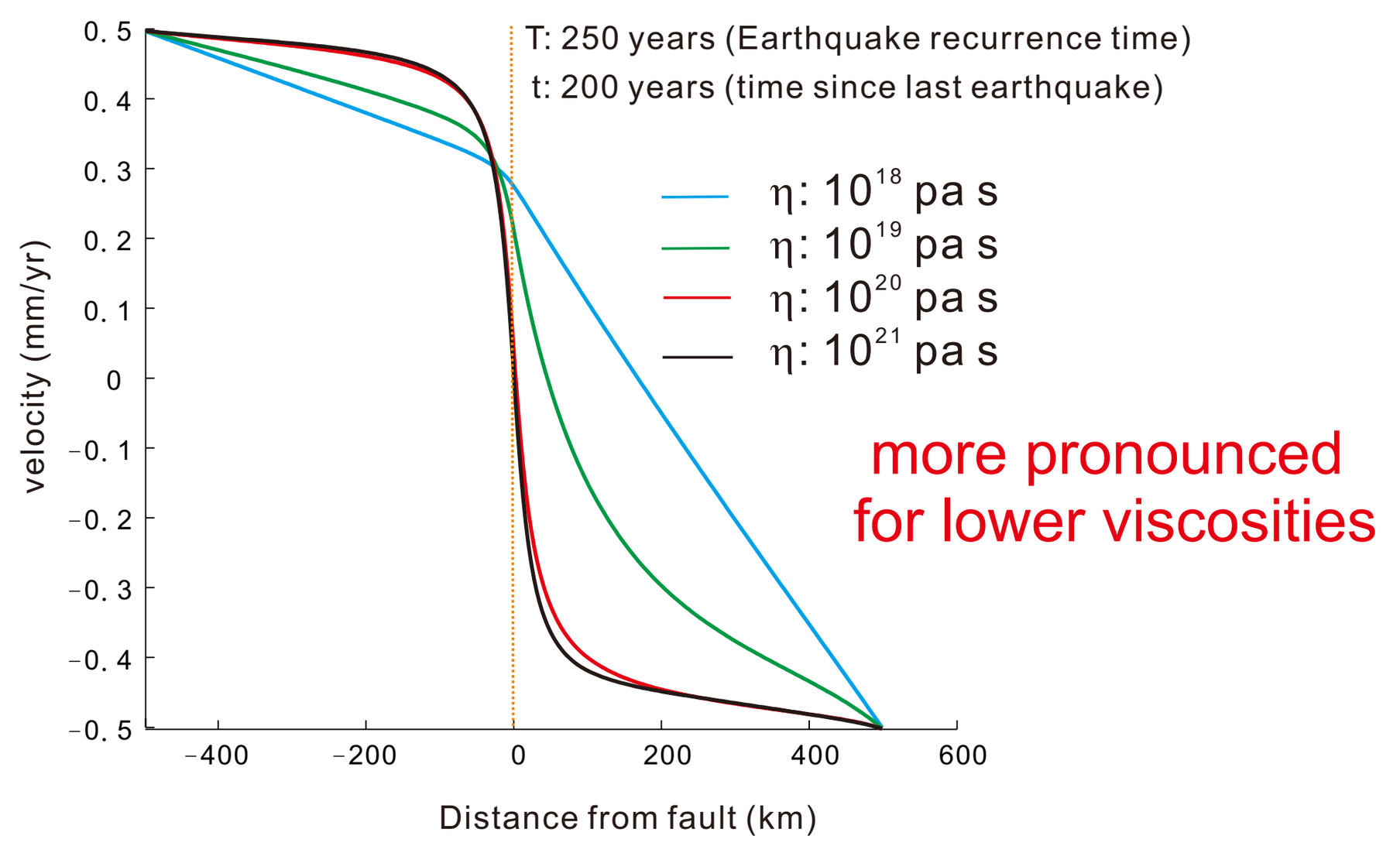


Asymmetry of Deformation

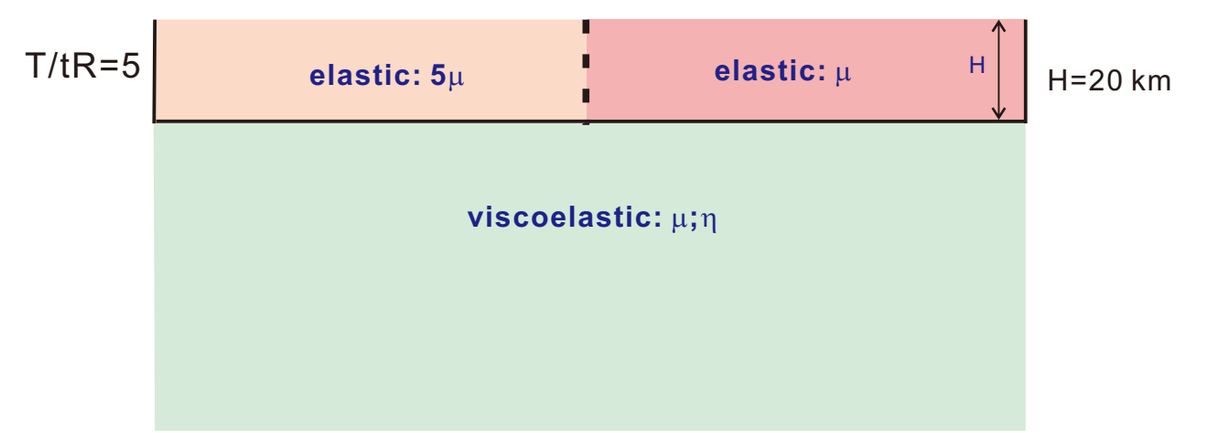
contrast in thickness

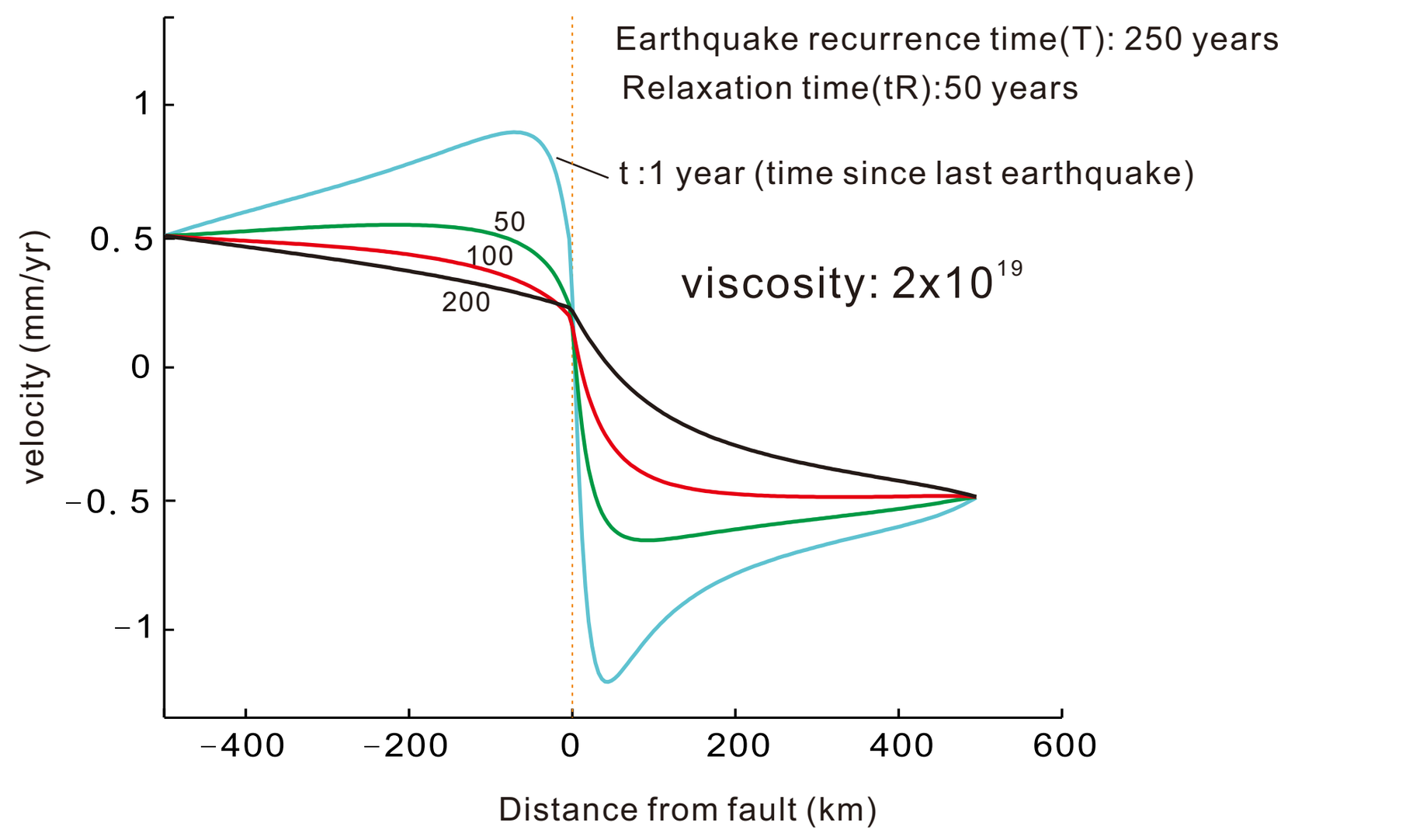


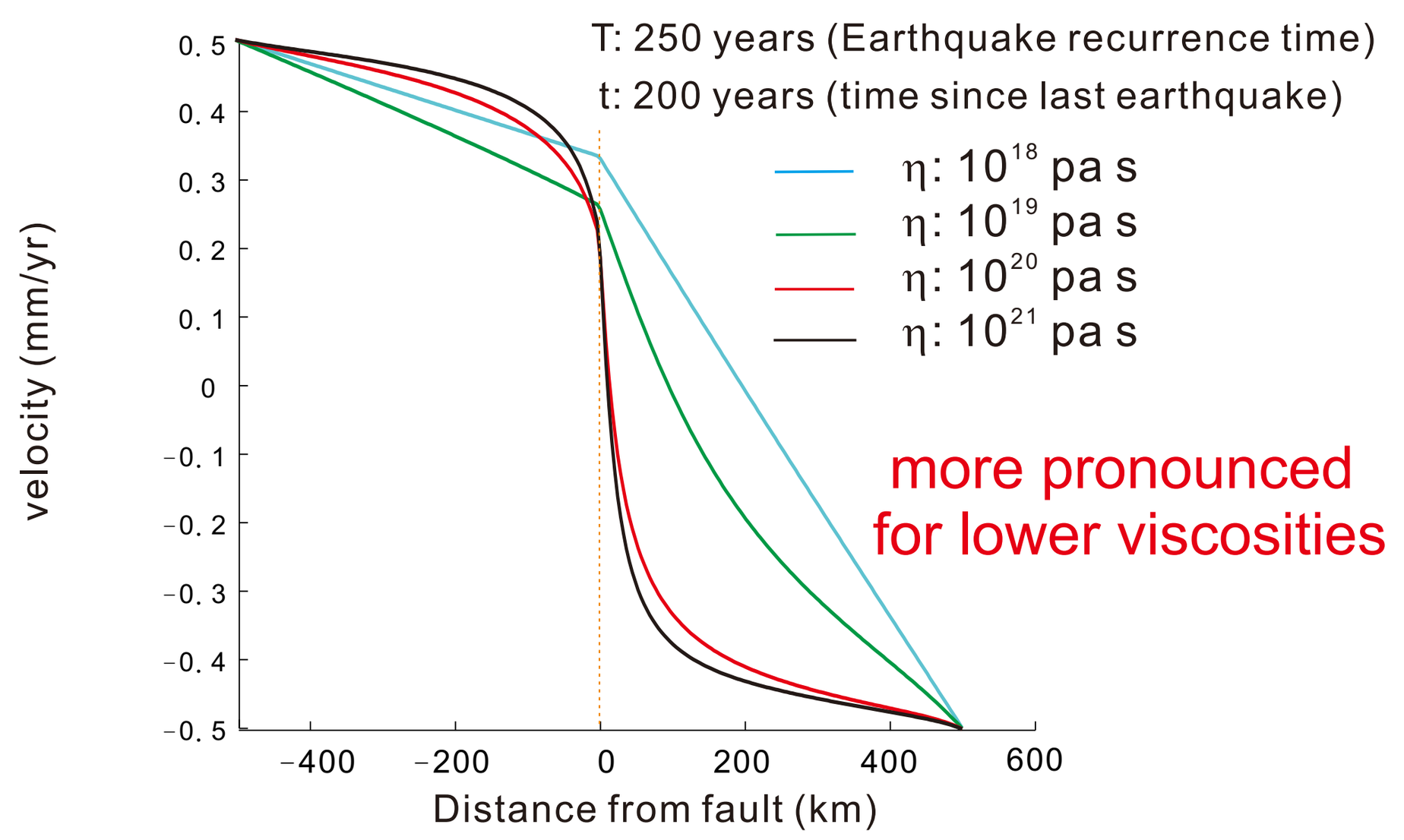




contrast in stiffness

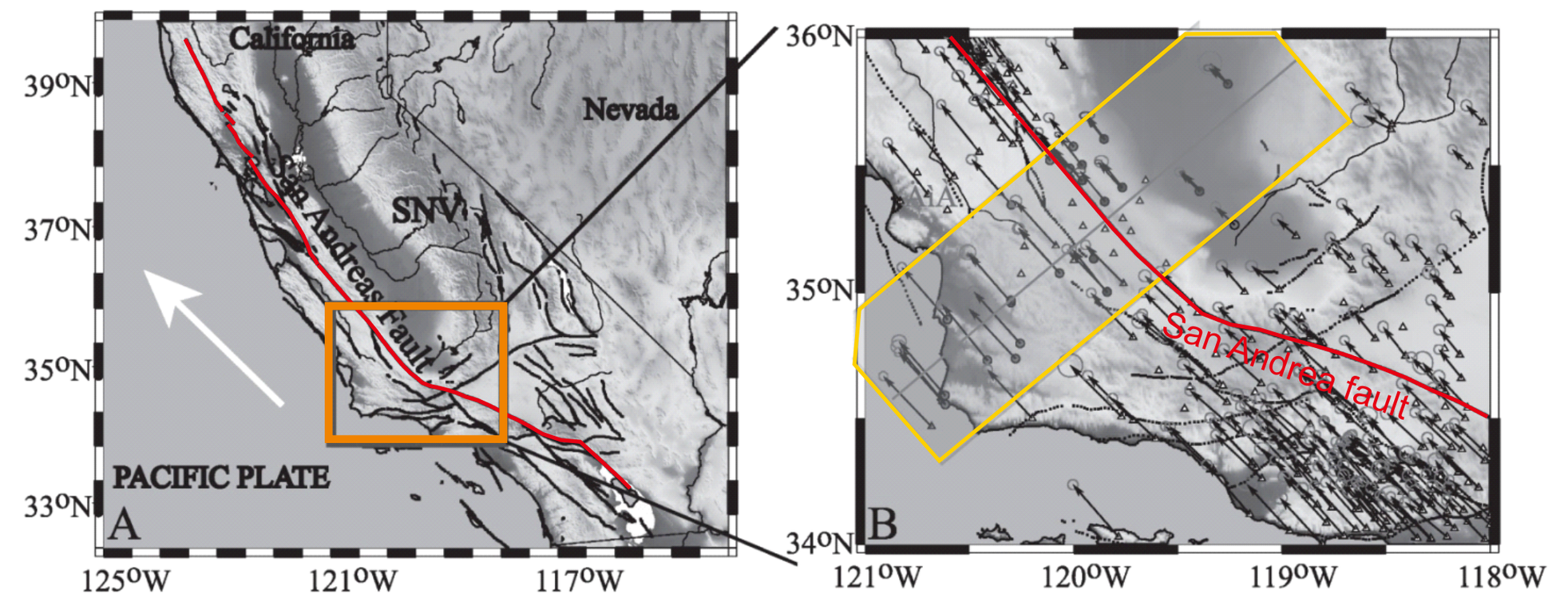




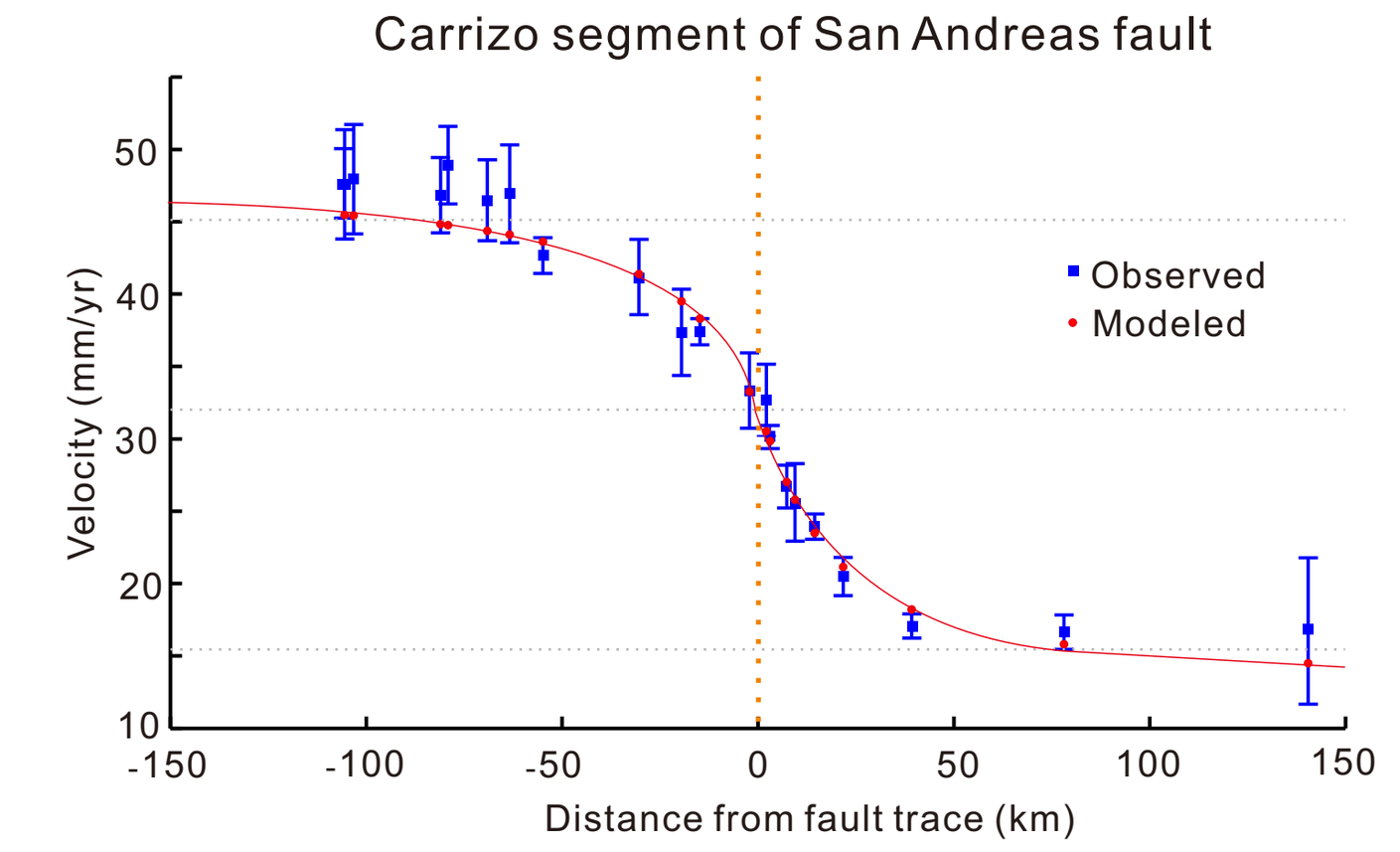


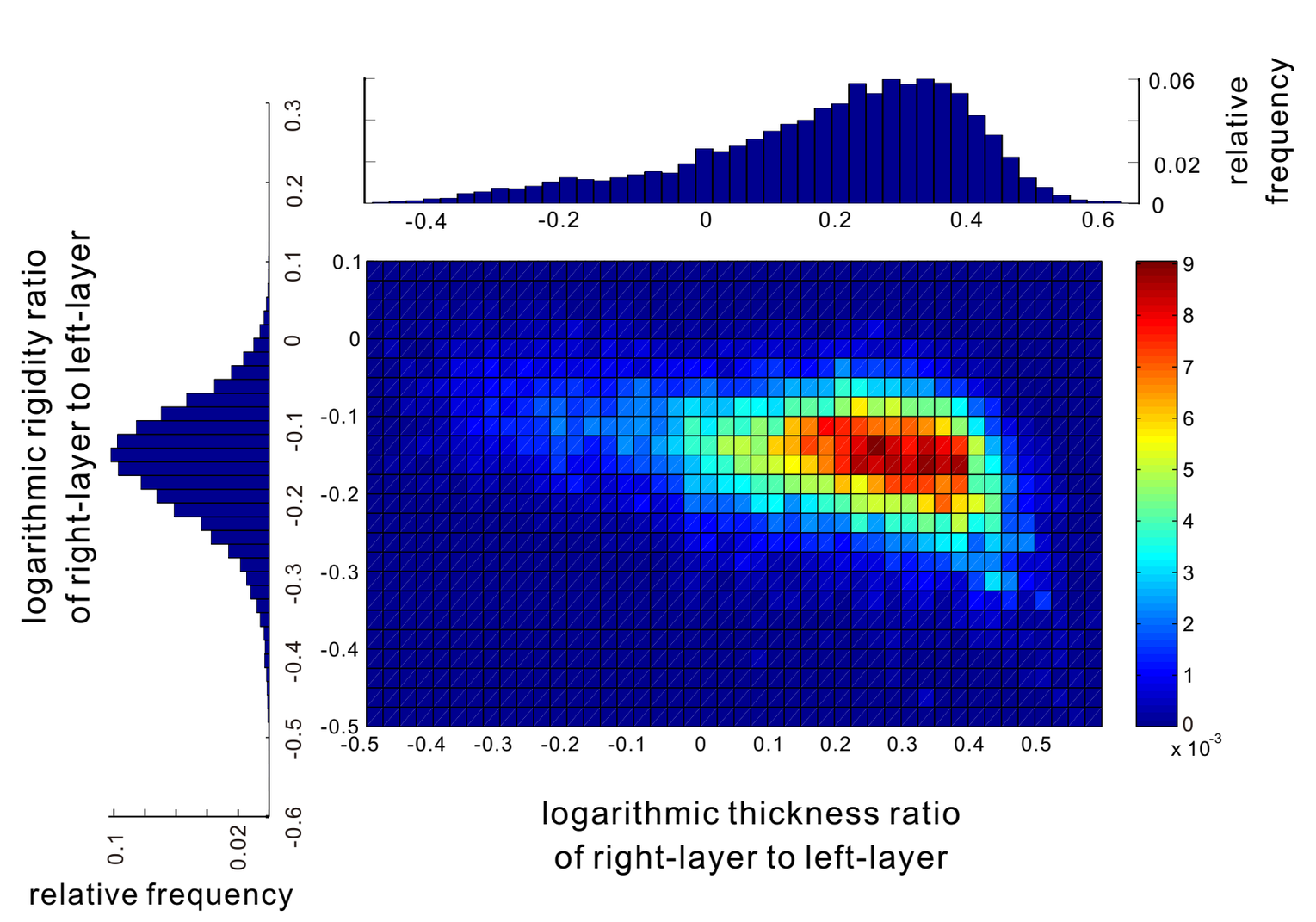
Carrizo segment of San Andreas Fault

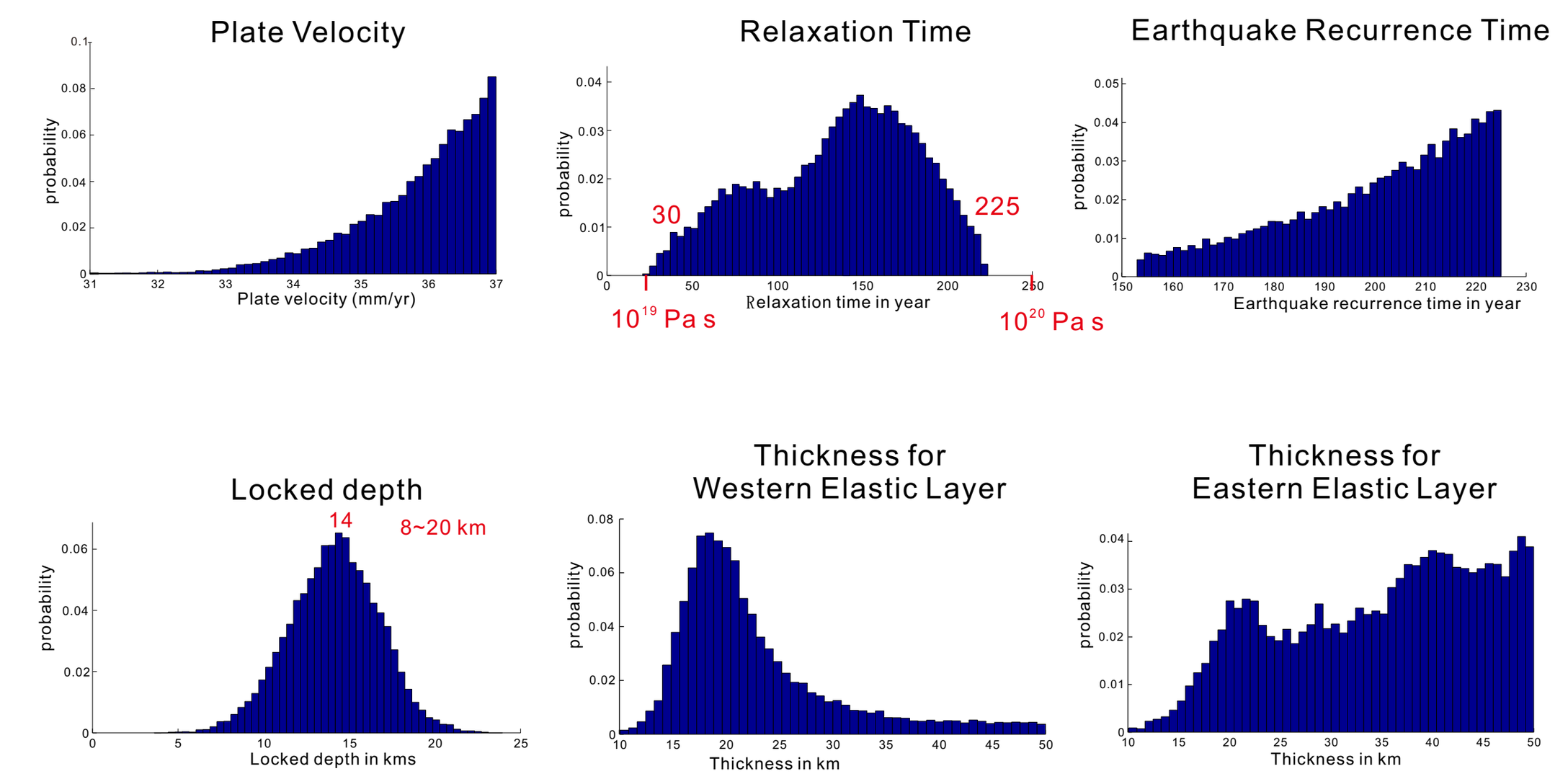
We investigate the Carrizo segment of the San Andreas fault where it has been debated whether the rigidity contrast or thickness difference between the elastic layers (i.e. lithospheric layers) to the southwest and to the northeast of the fault is responsible for observed asymmetry in the GPS velocity profile across the fault. Through a fully probabilistic scheme, we invert 1994~2003 GPS data for the long-term slip rate, thicknesses of elastic layers, fault locked depth, rigidity ratio of the two elastic layers, stress relaxation time and earthquake recurrence using geological and geophysical constraints.



(Schmalze et al., 2006)







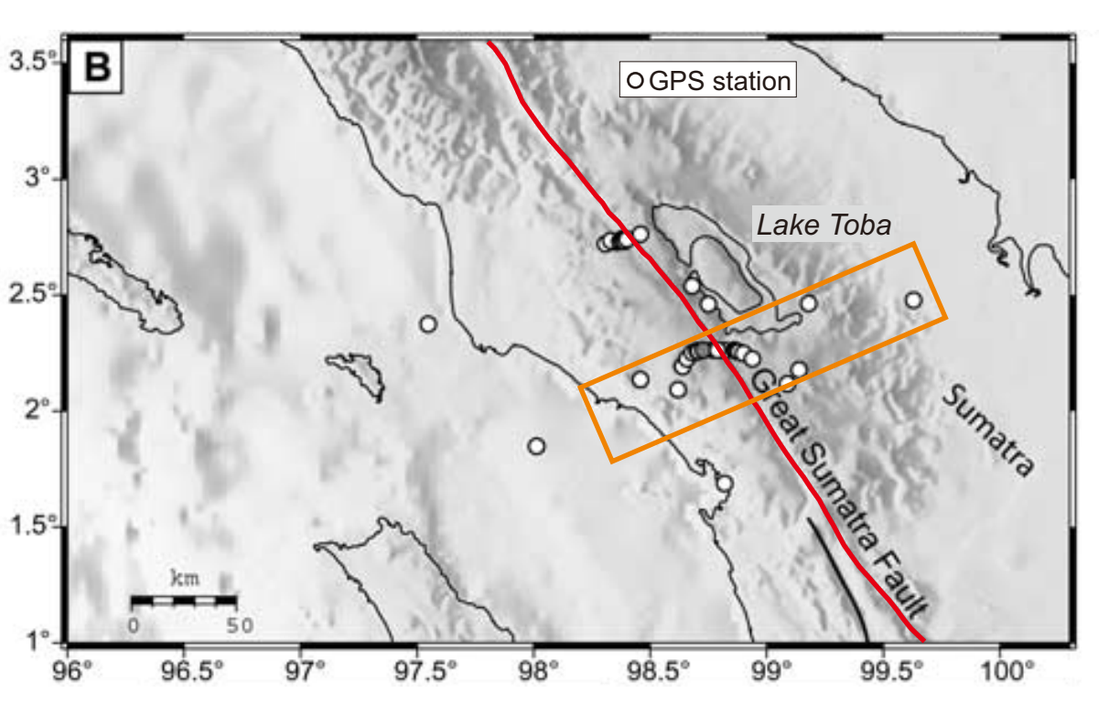
We find that the inversion favors a thicker layer on east side (2 times) but stiffer layer on west side (1.4 times); however, uniform thickness and stiffness cannot be ruled out. We estimate a fault locking depth of 8-20 km, but the earthquake recurrence time and mantle relaxationtime are not resolved.

Table: parameter constraint

Parameter		constaint	
item	unit	lower bound	upper bounder
long-term fault slip rate (Fsr)	mm/yr	31	37
thickness of right elastic layer (ThelR)	km	10	50
thickness of left elastic layer (ThelL)	km	10	50
thickness ratio of right to left elastic layer (Rth)	no		
locked depth (Ld)	km	0	mininum of elatic layers
logarithmic rigidity ratio (Lrr) rigidity ratio (Rr)	no	none	none
stress relaxation time (Tsr)	yr	0	maximum of Ter
earthquake reoccurence (Ter)	[T	153	225
interval in 2003 (data collection) since the latest earthquake in 1857 (tobs)	[T	HZGF XCNWG QH	

Renun segment of the Sumatra fault

We also investigate the Renun segment of the Sumatra fault where the 1989-1996 GPS velocity profile across the fault is distinctly asymmetric.



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

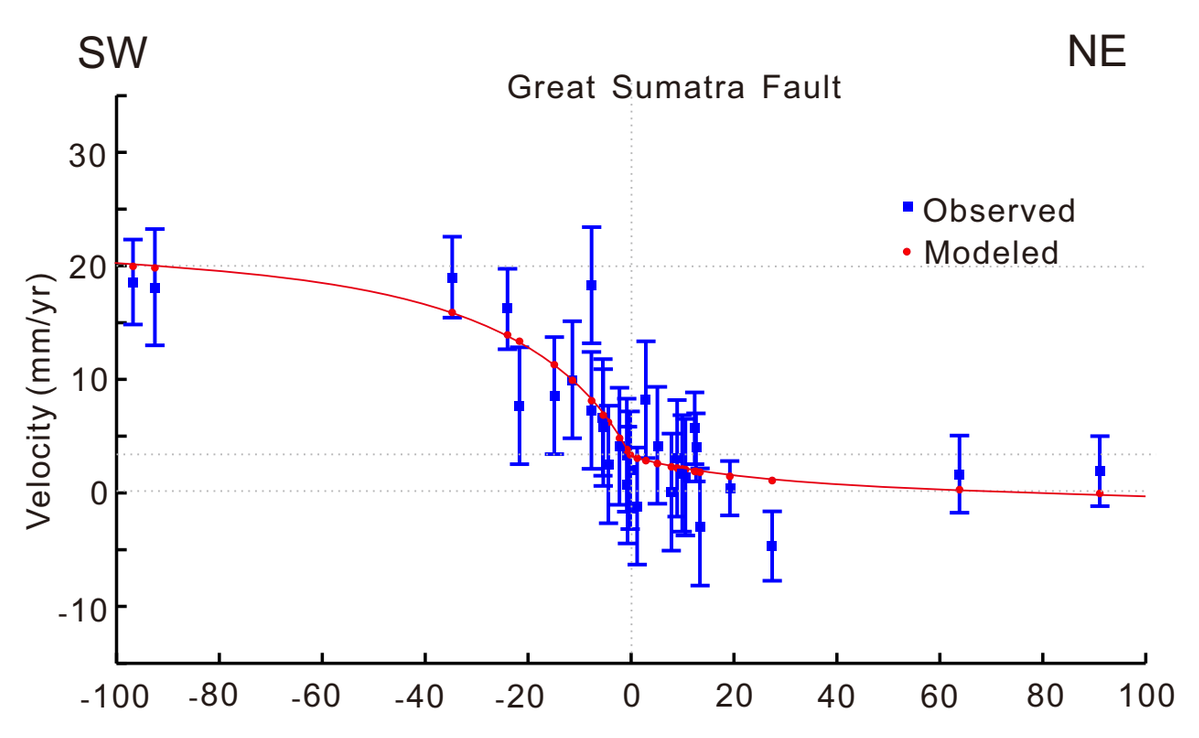
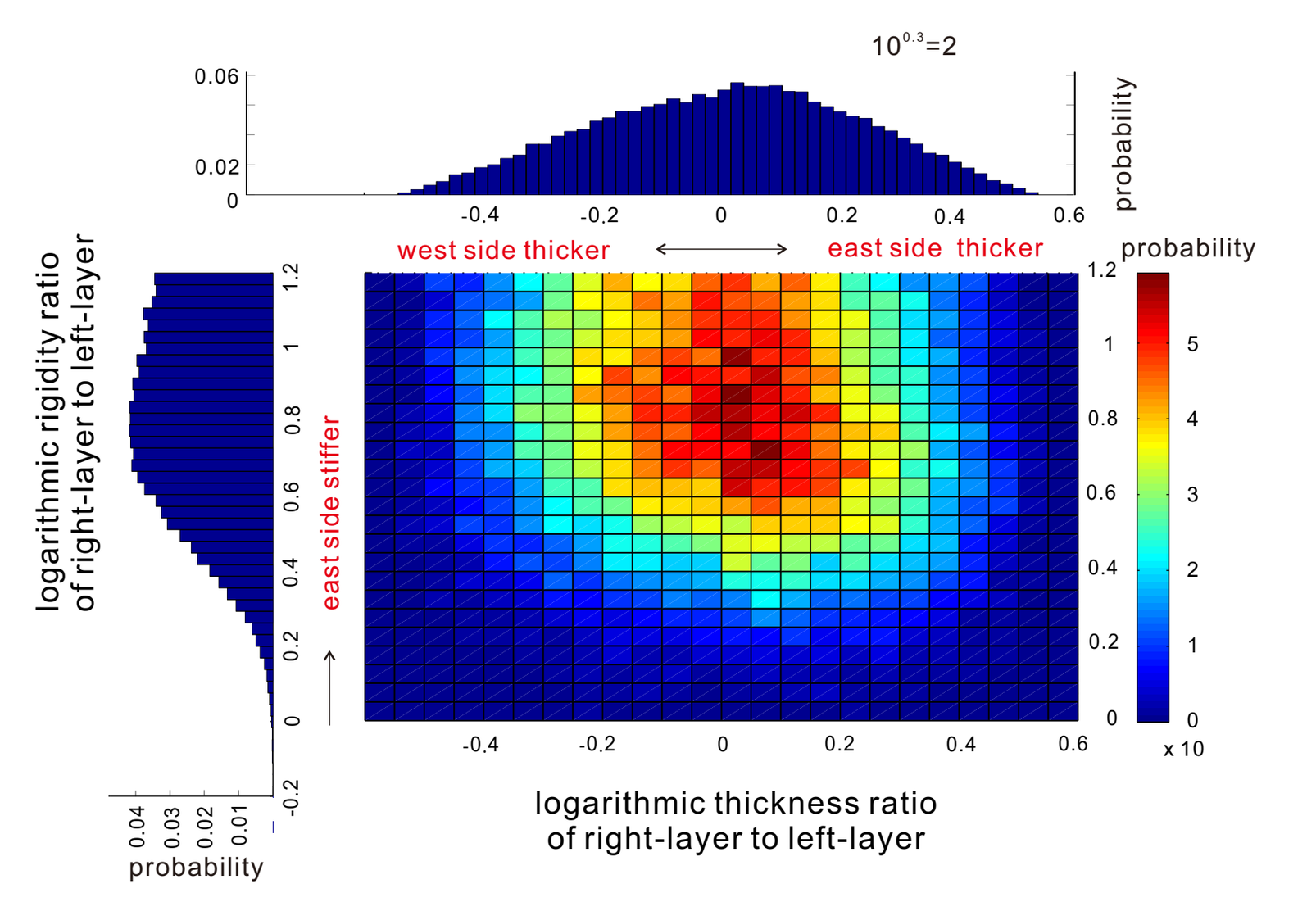
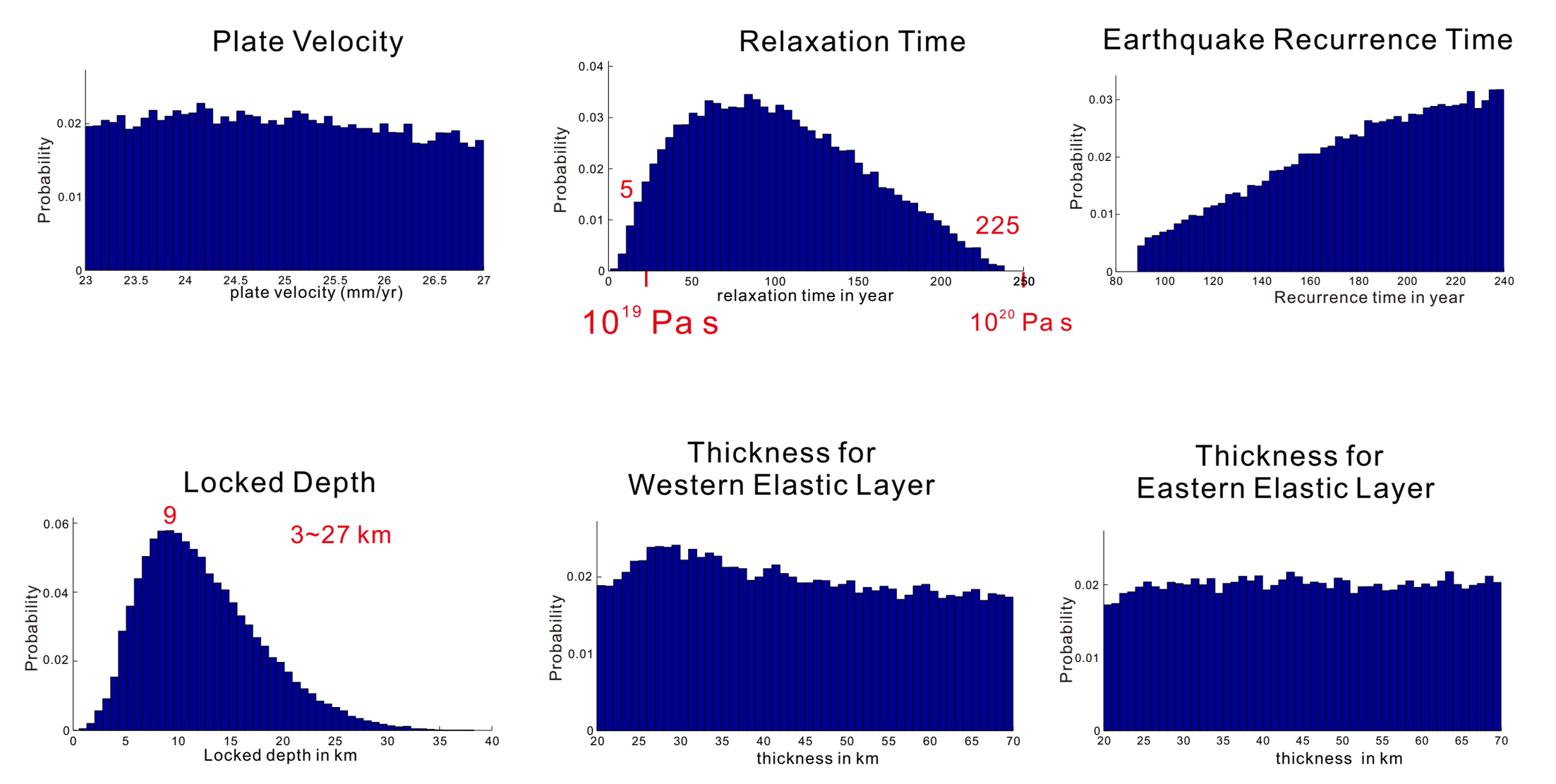


Table: parameter constraint

Parameter			constaint	
item	unit		lower bound	upper bounder
long-term fault slip rate (Fsr)[1]	mm/yr	27	23	27
thickness of right elastic layer (ThelR)[2]	km	62	10	70
thickness of left elastic layer (ThelL)[2]	km		10	70
thickness ratio of right to left elastic layer (Rth)	no			
locked depth (Ld)[3]	km	9		
logarithmic rigidity ratio (Lrr) rigidity ratio (Rr)[4]	no	3	no	no
stress relaxation time (Tsr)	yr		>0	maximum of Ter
earthquake reoccurence (Ter)[5]	yr	160	89	240
years from last main earthquake (tobs)[6]	yr	88	fixed as 88	

1Sheih et al. (1991; 2000) esitmated the value of long-term fault slip as 27mm/yr. McCaffrey et al. (2000) found arc-parellel velocities of 23-27 mm/yr for the northern Sumatra region.
2 Polliz et al. (2006) adopted an elastic layer of 62 km thick in their model.
3 Le Pichon et al (2005) fixed the locked depth to 9 km in conformity with Genrich et al. (2000)
4 Le pichon et al (2005) got the favored rigidity ratio of 3.
5 Bellier et al (1997) infer a northward increase of hazard along the SFS (Sumatra fault system) with recurrence intervals of 400±200 years for a maximum expected Mw=7.2 event in southern Sumatra and of 160±80 for a Mw=7.7 maximum expected earthquake at 2°N.
6 Sieh et al (2000) reported the Renun segment (i.e. the segment of GSF in this region) the source of three major earthquakes early in the twentieth century. The possible biggest one occurred on April. 1. 1921

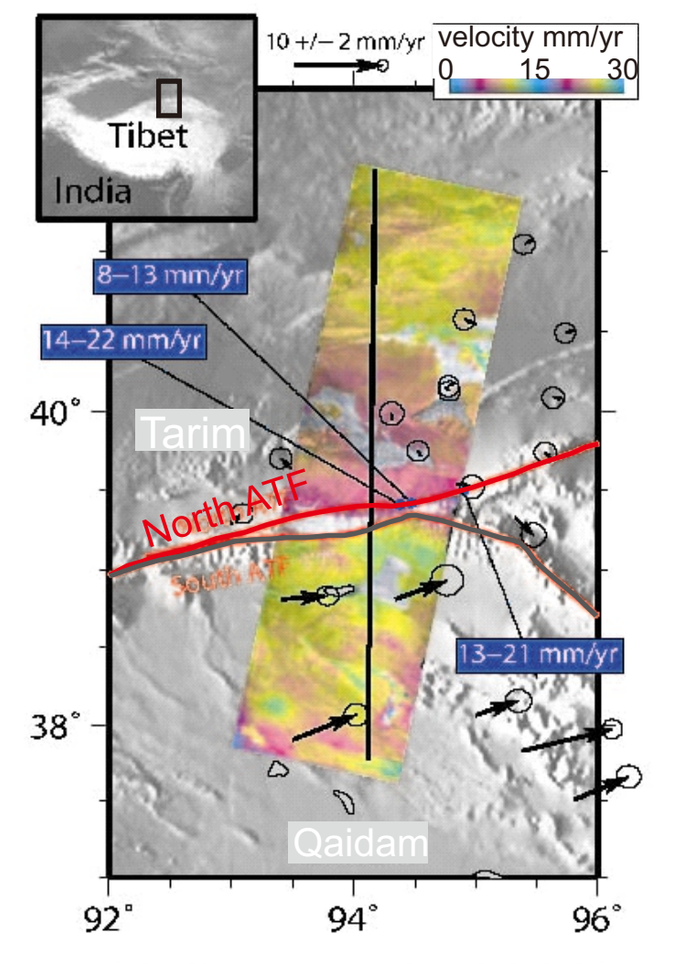




Inversion results show the elastic layer on the east side must be stiffer than the west side but the elastic thicknesses are not resolvable. We estimate a fault locking depth of 3-27 km, but the earthquake recurrence time and mantle relaxation time are not well resolved, either.

Altyn Tagh fault

We also investigate the segment of Altyn Tagh fault, the northern border of the Tibetan plateau between the Tarim and the Qaidam basins, where surface velocity (projected to fault-parallel direction) obtained from a stack of 15 interferograms using ERS and ENVISAT radar data covering the 1995–2006 period is distinctly asymmetric. We examine the possibility of the existence of low-viscosity lower crust (a channel) in the Tibetan plateau which has been debated.



(Jolivet et al., 2008)

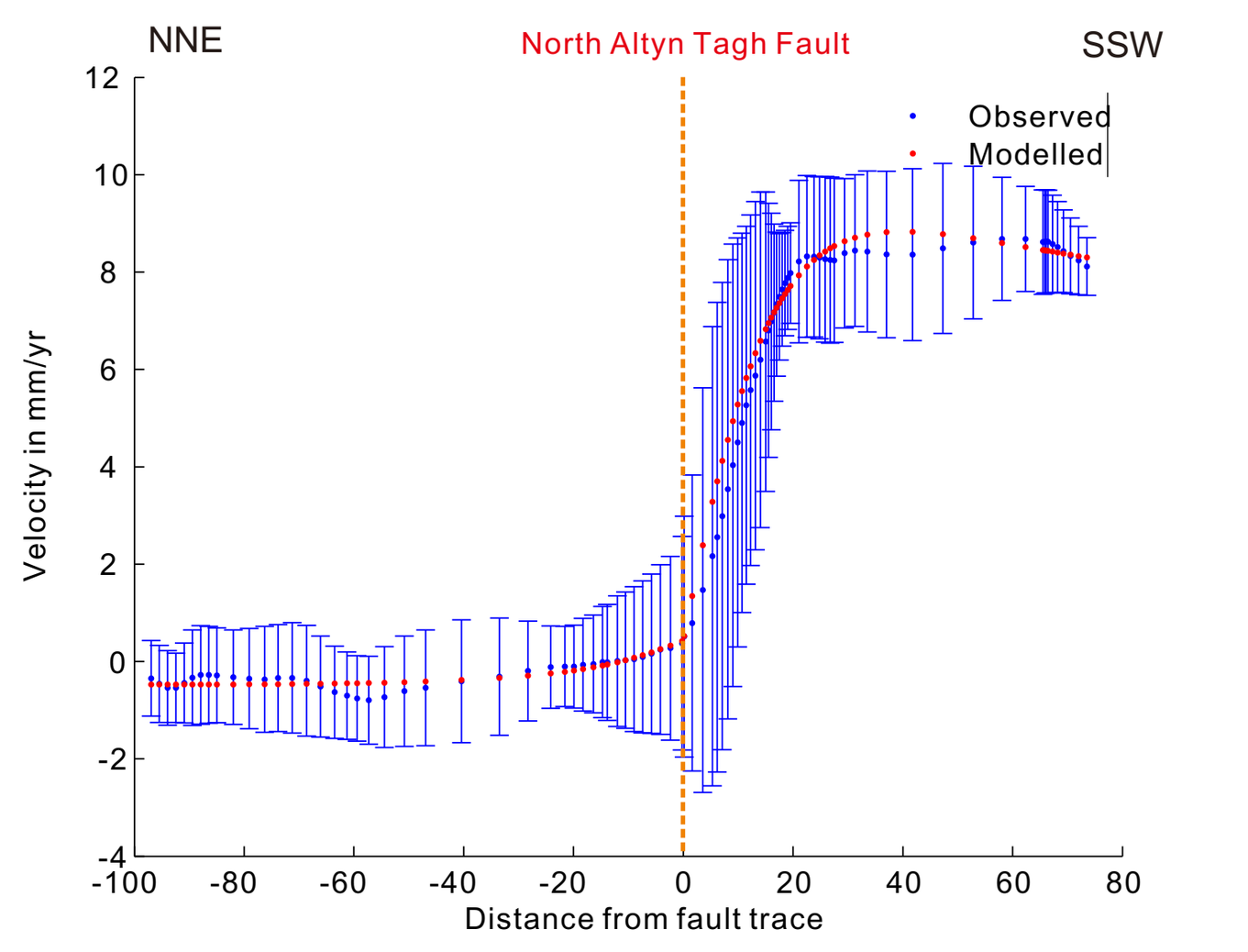


Table: parameter constraint

Parameter			constraint	
item	unit		lower bound	upper bounder
long-term fault slip rate (Fsr)	mm/yr	17.8[a]	2[b]	20.4[a]
thickness of right elastic layer (ThelR)	km		10	70
thickness of left elastic layer (ThelL)	km		10	70
thickness of low viscou layer	no	fixed as 10 (arbitrary)		
locked depth (Ld)	km			>min(ThelR,ThelL)
logarithmic rigidity ratio (Lrr)[c] rigidity ratio (Rr)	no		-1.2	1.2
stress relaxation time (tr_lc)	yr		10	
stress relaxation time (ts_um)	yr		greater than tr_lct but small than Tes	
earthquake reoccurence (Ter)[d]	yr		300	1400
years from last main earthquake (tobs)	yr		100	

[a]Meriaux et al. (2005) estimated an average Holocene rate of 17.8 ± 3.6 mm/yr.
[b]Meyer et al. (1996) attained slip rate is 4 ± 2 mm/yr for the eastermost of the Altyn fault, east of 96°E.
[c]Le Pichon et al. (2005) indicated as the typical range of average values of the elastic parameter is an order of magnitude from mantle to sediment, (e.g., from peridotite (14~16 x 1010 Pa) to shale (1-3 x 1010 Pa), the ratio is unlikely to exceed an order of magnitude anywhere.
[d] Washburn et al. [2001] yield recurrence intervals of 0.7± 0.4k.y. and 1.1± 0.3 k.y.

amount of sample: 362410

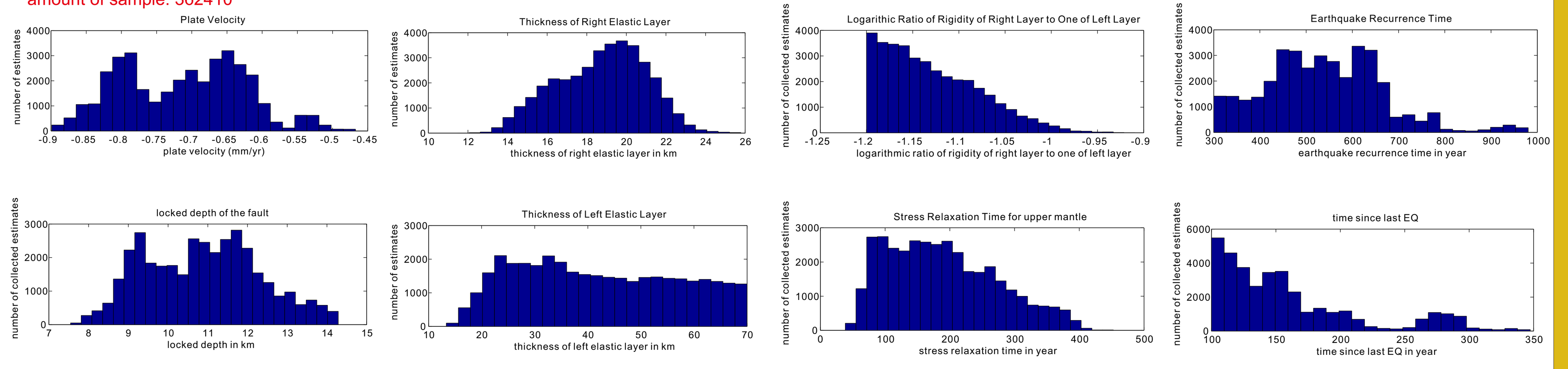


Plate Velocity
Thickness of Right Elastic Layer
Logarithic Ratio of Rigidity of Right Layer to One of Left Layer
Earthquake Recurrence Time
locked depth of the fault
Thickness of Left Elastic Layer
Stress Relaxation Time for upper mantle
time since last EQ

The graphs above are results for a case with a specified low viscosity of lower crust. Our preliminary inversion result concluded from all cases we ran shows the northern elastic layer (Tarim Basin) must be stiffer and thicker than the southern one (Tibetan Plateau) but the viscosity of the mid-custal Tibetan channel in not resolvable. We estimate a fault locking depth of 8.5-13.5 km, the earthquake recurrence time of 550-1400 yrs, and a mantle relaxation time of 140-600 yrs.