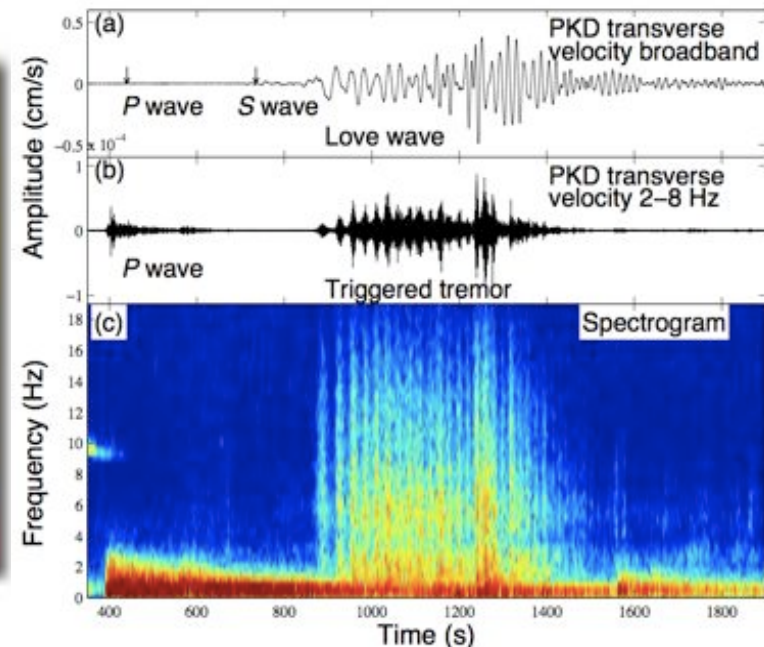
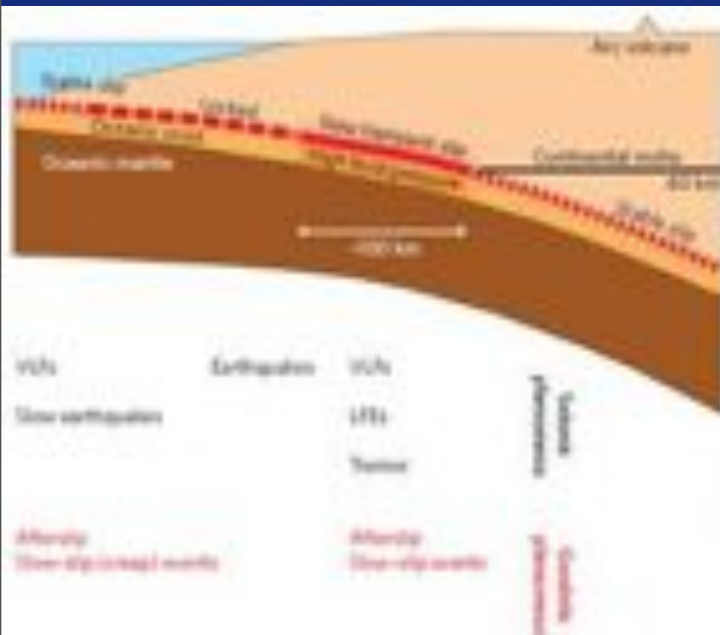


Tremor, Triggering and Slow-Slip Phenomena

Zhigang Peng

School of Earth and Atmospheric
Sciences

Georgia Institute of Technology



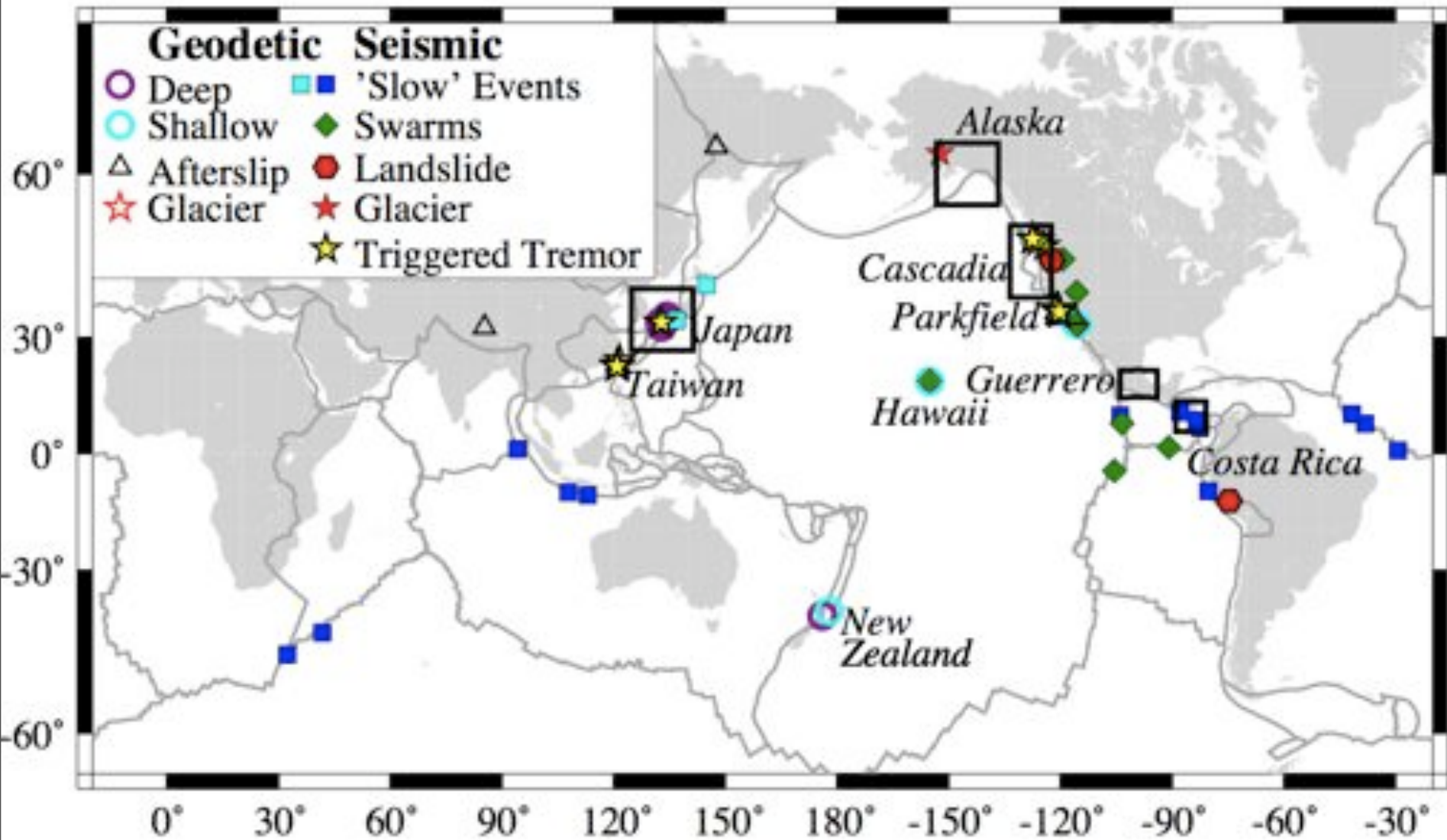
Outline

- Remote triggering of tremor around the San Andreas Fault (Peng et al., 2008, 2009, 2010; Shelly et al., 2010)
- Remote triggering of tremor beneath the central Range in Taiwan (Peng and Chao, 2008; Tang et al., 2010; Chao et al., submitted)

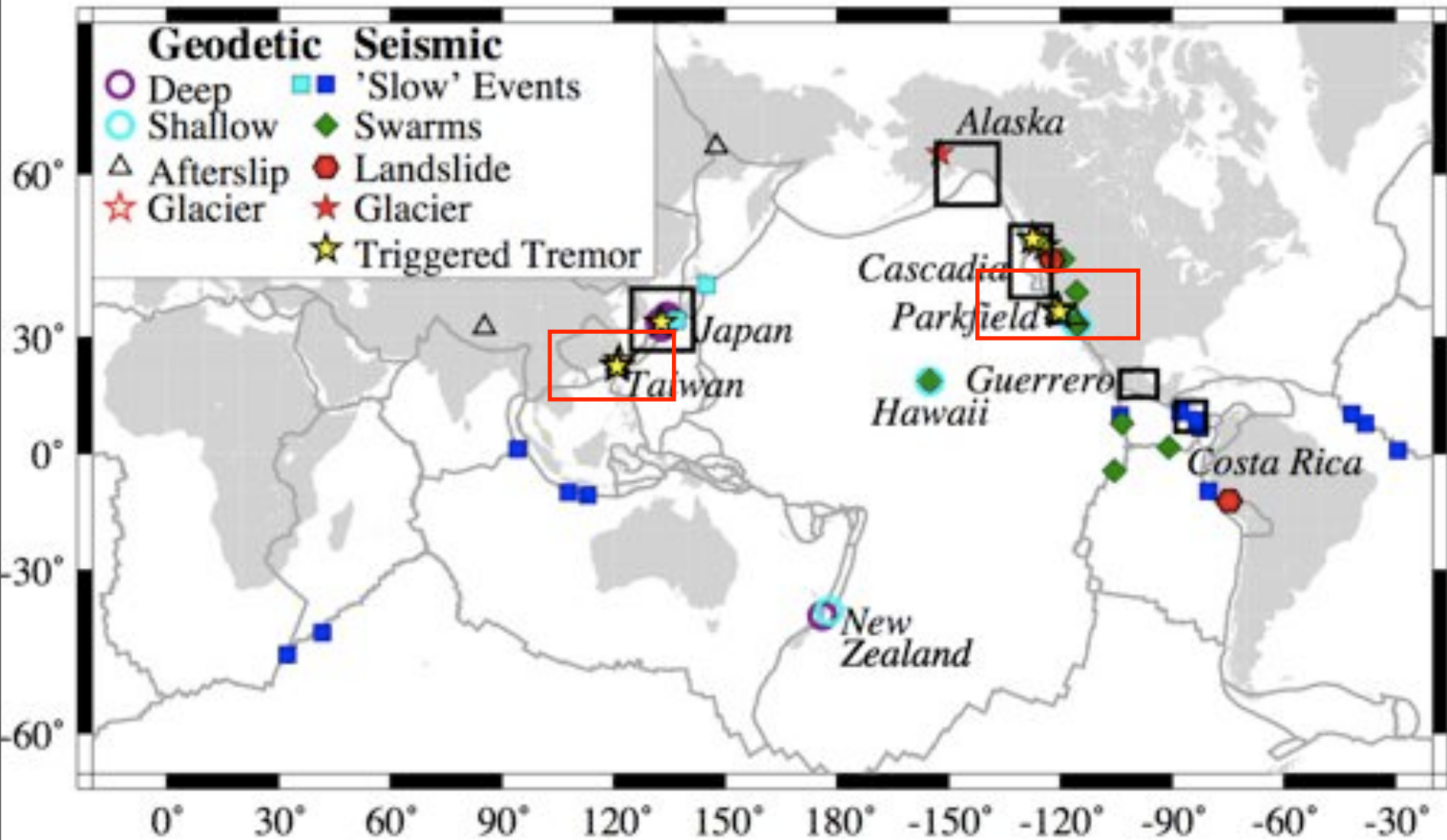
Acknowledgements

The work is supported by the NSF's Geophysics and CAREER programs.

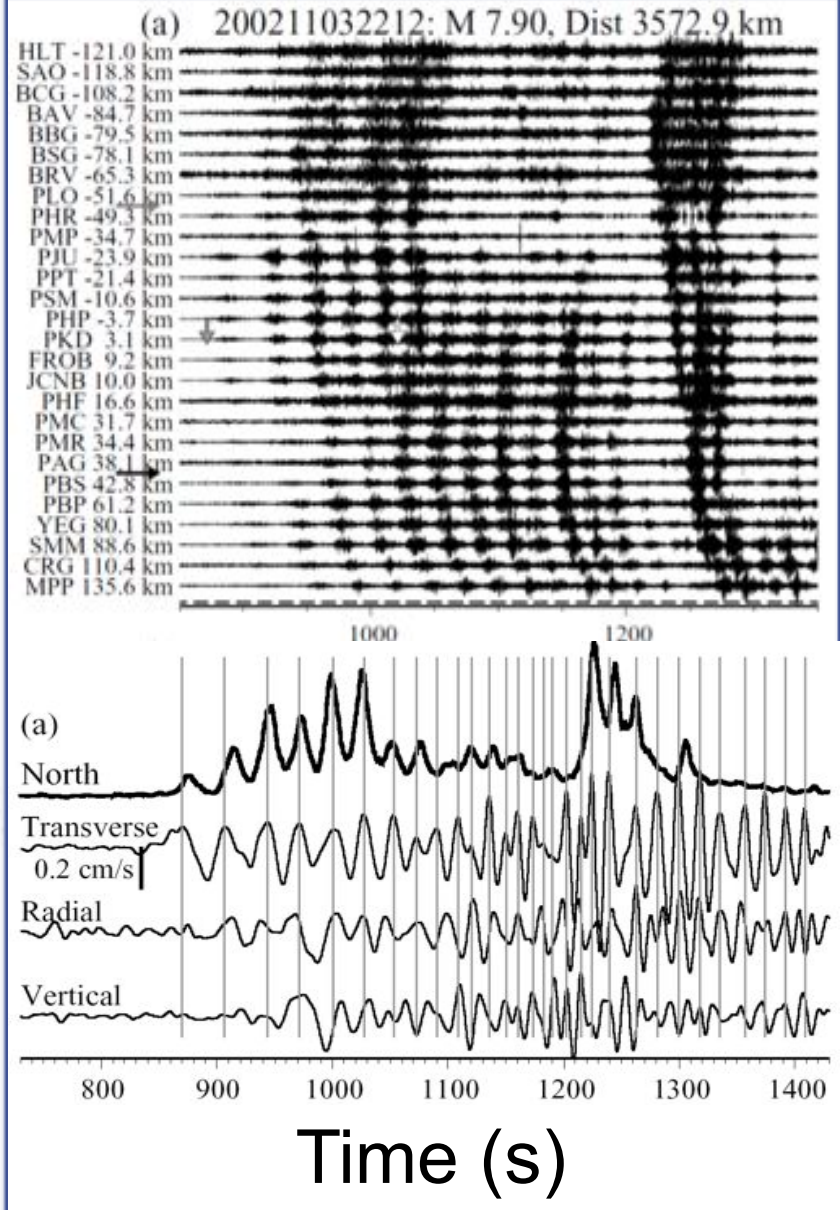
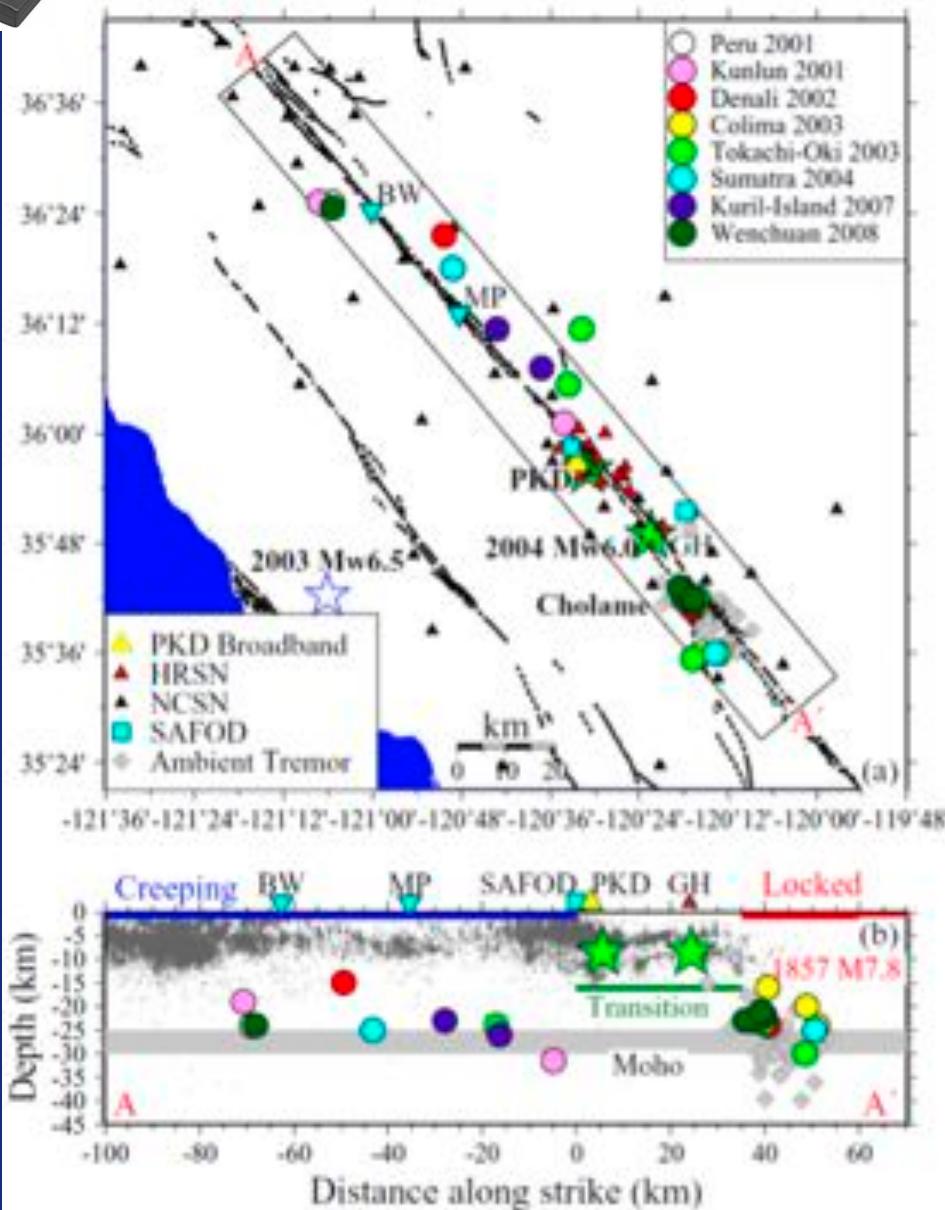
Maps showing where tremor and slow-slip events have been observed (Peng and Gomberg, NCEO, 2010)



Maps showing where tremor and slow-slip events have been observed (Peng and Gomberg, NCEO, 2010)



What we already knew about triggered tremor



Peng et al. (JGR, 2009)

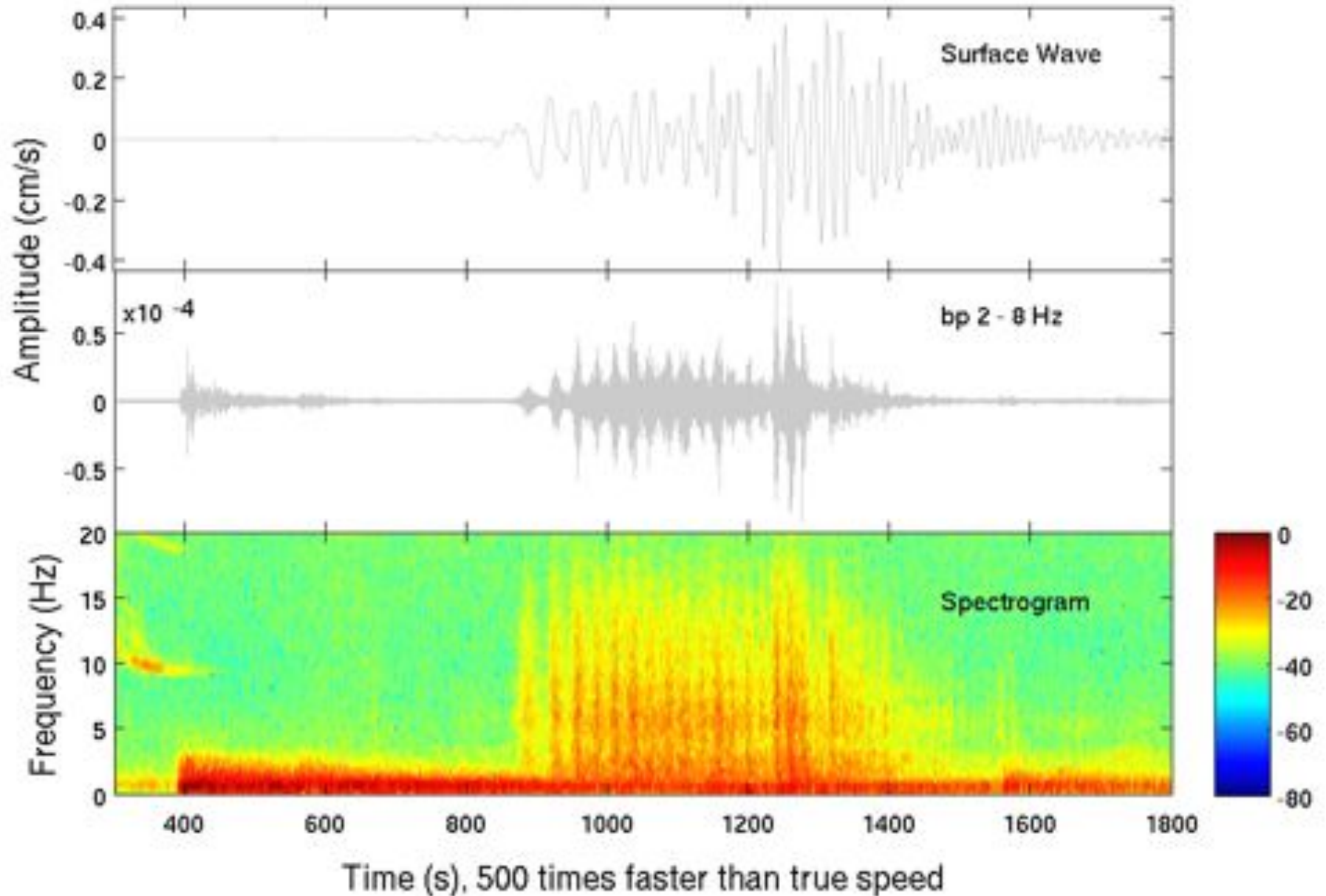
Peng et al. (GRL, 2008)

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11/01/10

Monday, November 1, 2010

2002 Mw7.8 Denali earthquake triggered tremors
at Parkfield, CA; Station: BK.PKD



Peng et al. (2008, 2009)



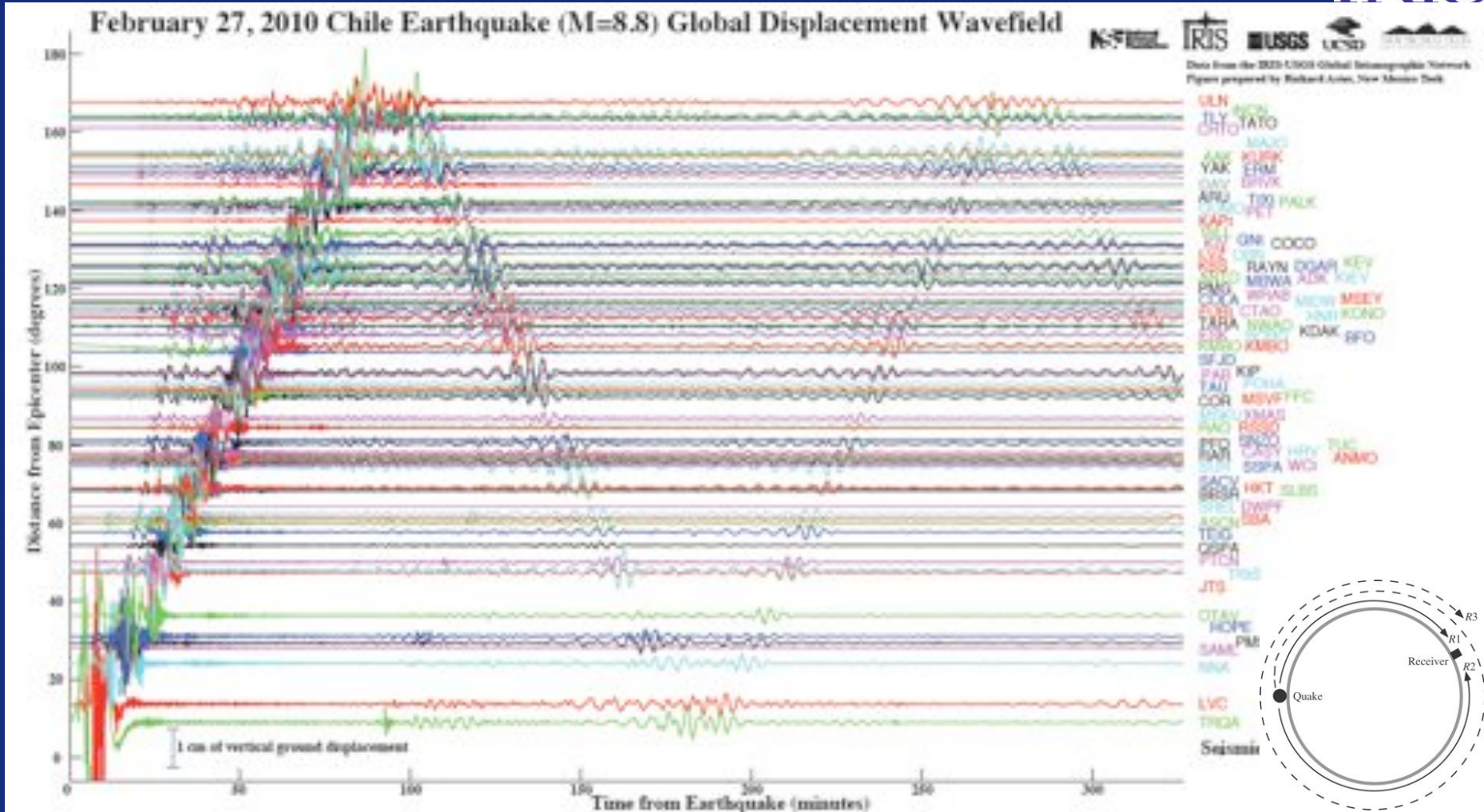
What we don't know about triggered tremor

- Does triggered tremor consist of many low-frequency earthquakes (LFEs) like ambient tremor (Beroza and Ide, Science, 2009)?
- Does triggered tremor occur at the same places (depth) as the ambient tremor, with similar mechanism, except that the driving forces are different (Beroza and Ide, Science, 2009)?
- Can the triggered tremor be explained by the 'clock-advanced' model (Gomberg, JGR, 2010)?
- What are the relationship between 'triggered' tremor and slow-slip events (Smith and Gomberg, JGR, 2009)?



Magnitude 8.8 OFFSHORE MAULE, CHILE

Saturday, February 27, 2010 at 06:34:17 UTC

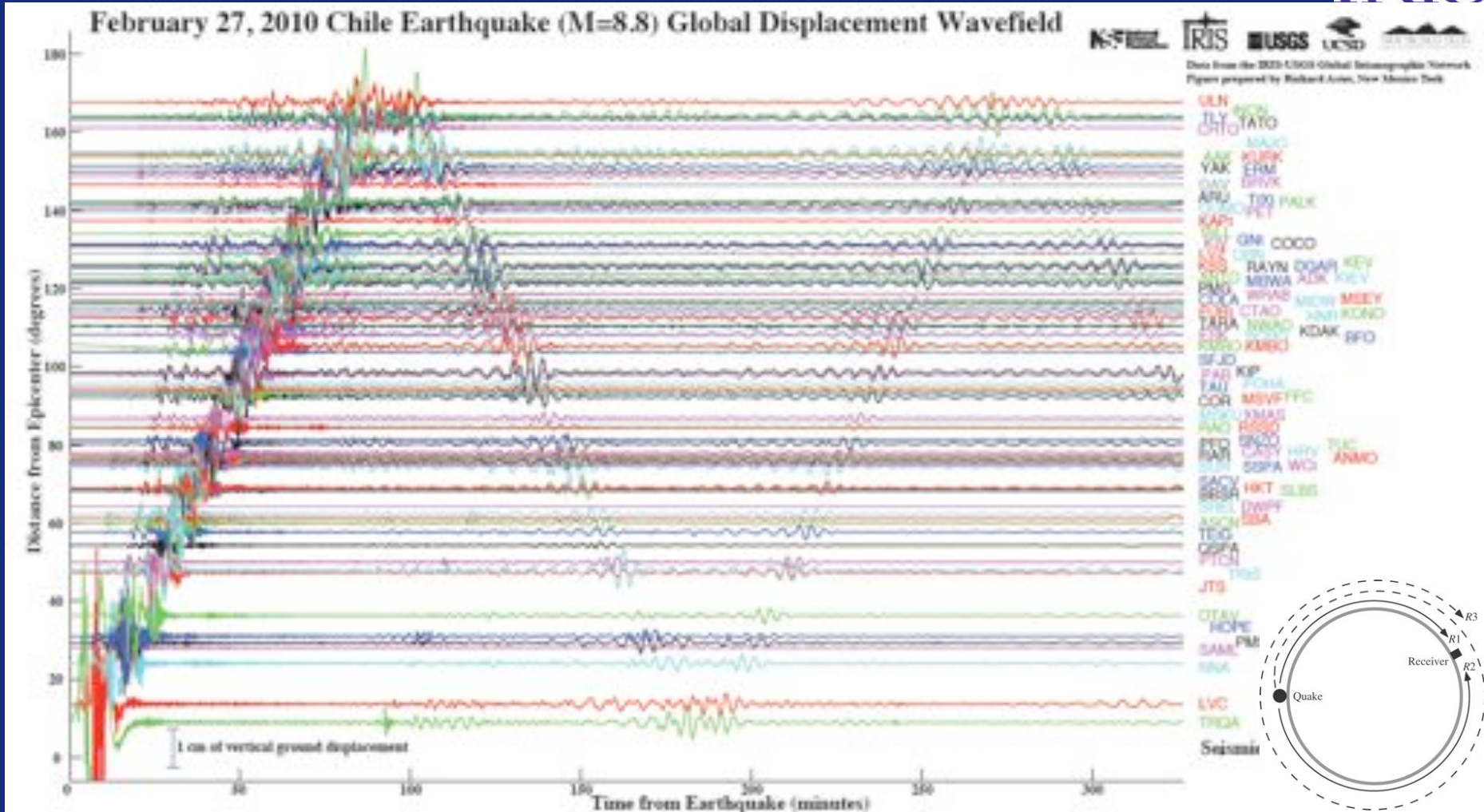


Global record section

The global surface wave displacements around the globe are shown. The closest shown station is in Argentina and the most distant one is in Mongolia. A 6.9 aftershock is visible for comparative scale near 90 minutes after the mainshock.

Magnitude 8.8 OFFSHORE MAULE, CHILE

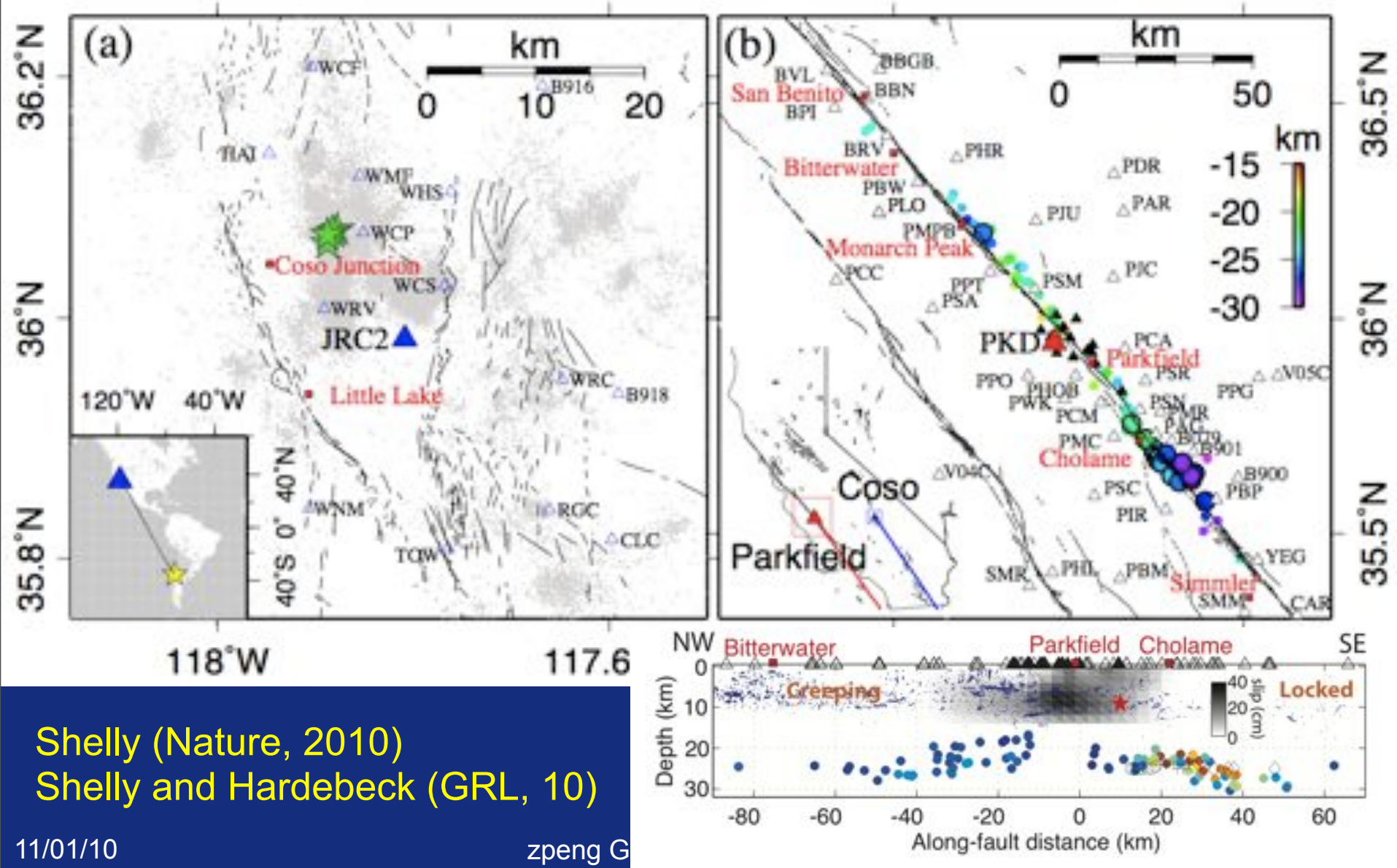
Saturday, February 27, 2010 at 06:34:17 UTC



Global record section

The global surface wave displacements around the globe are shown. The closest shown station is in Argentina and the most distant one is in Mongolia. A 6.9 aftershock is visible for comparative scale near 90 minutes after the mainshock.

Remotely triggered microearthquakes and tremor in Central California following the 2010 Mw8.8 Chile Earthquake (Peng/Hill/Shelly/Aiken, GRL, in review)



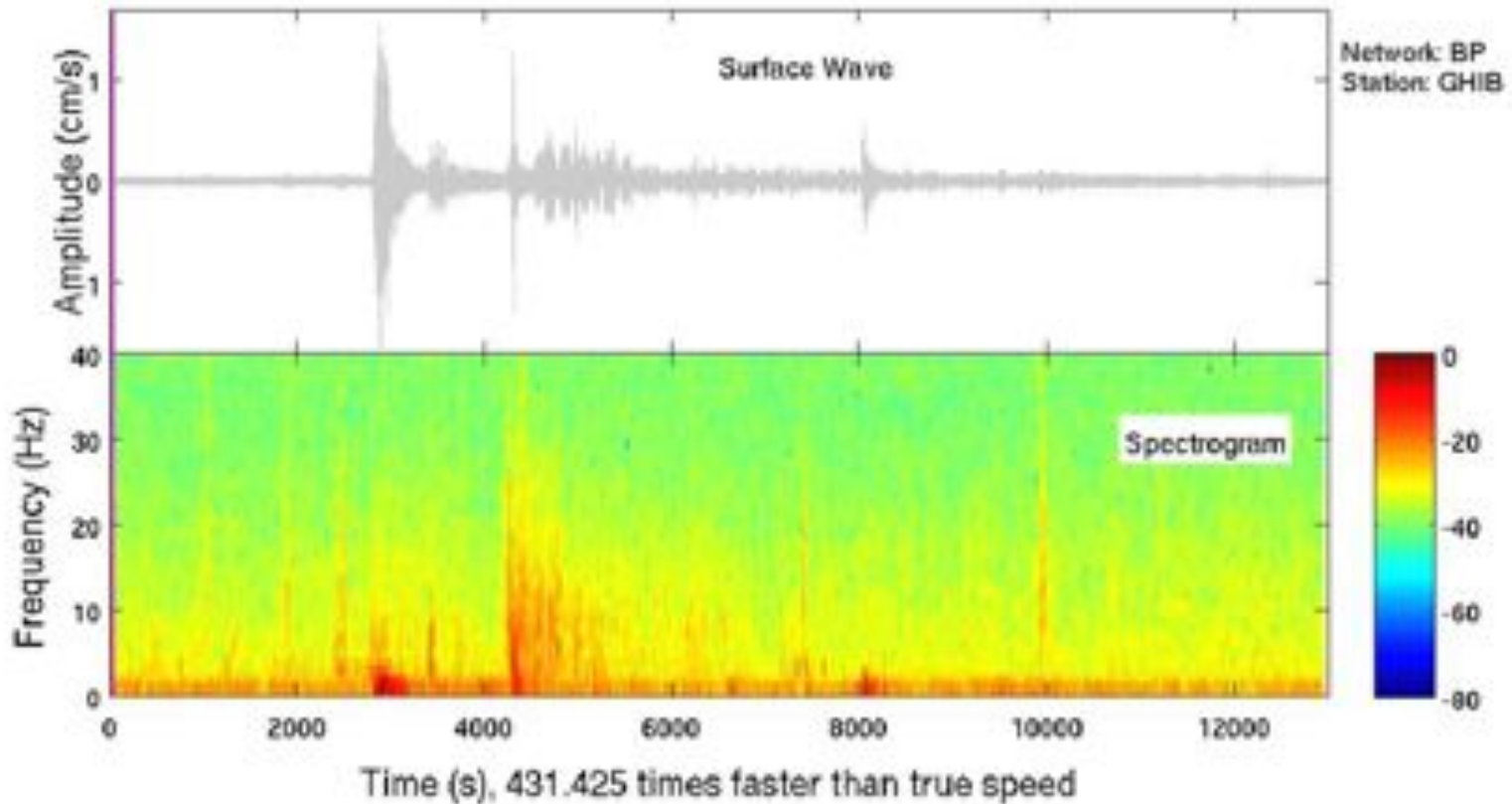
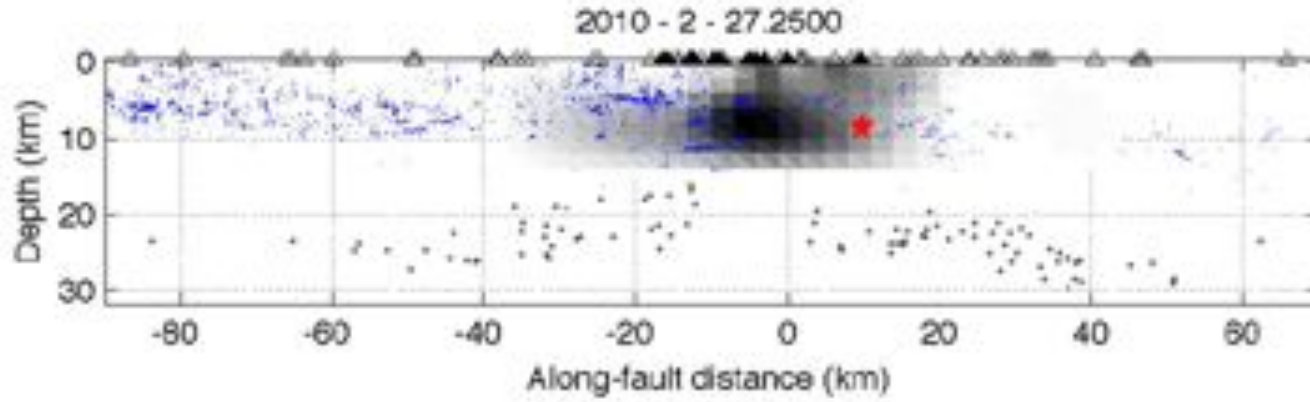
Shelly (Nature, 2010)
Shelly and Hardebeck (GRL, 10)

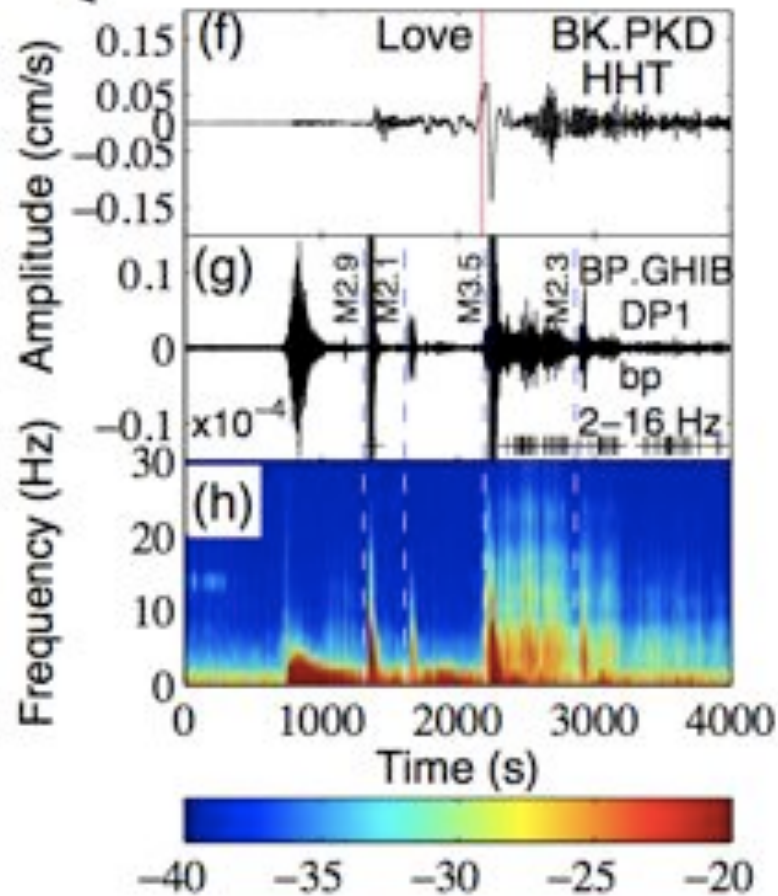
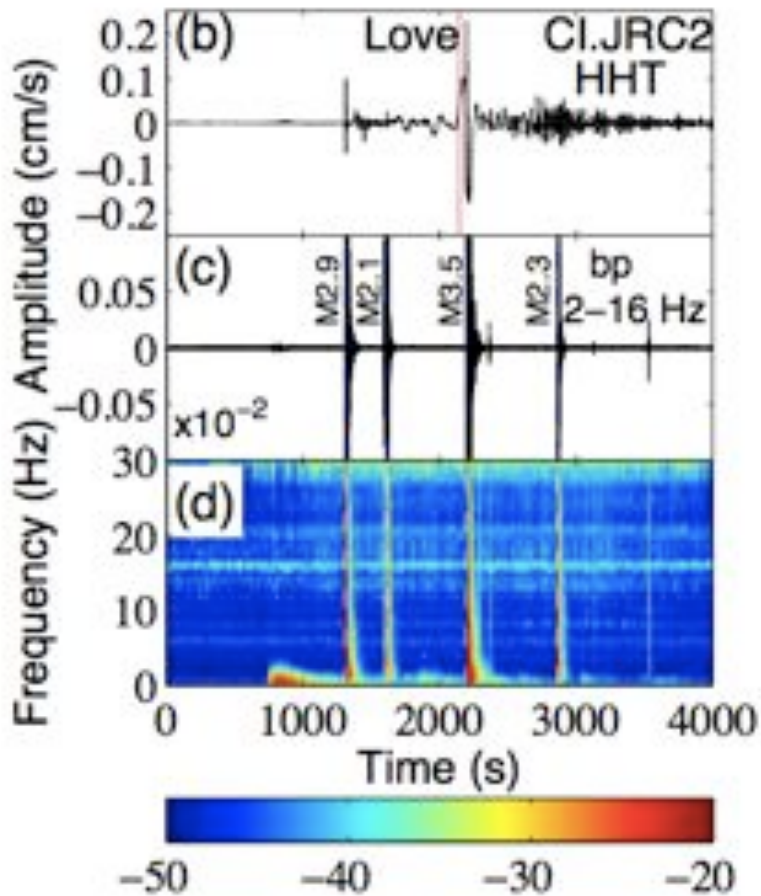
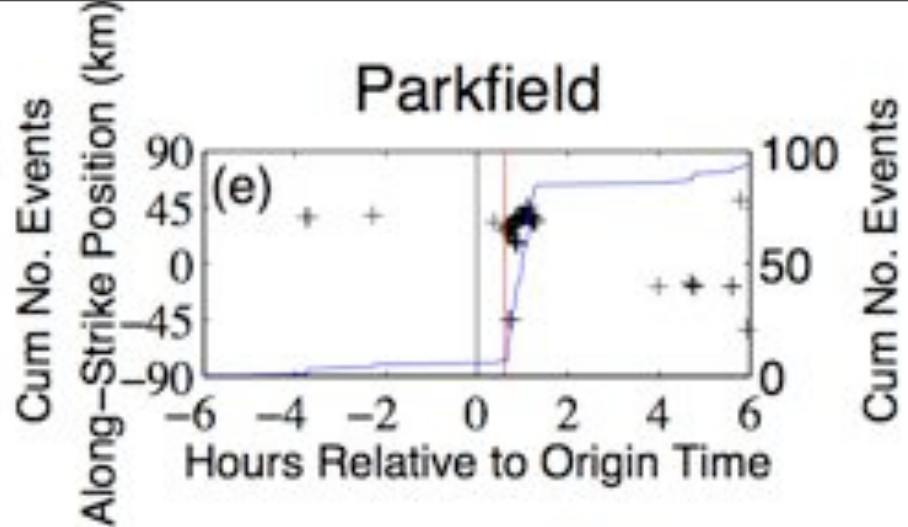
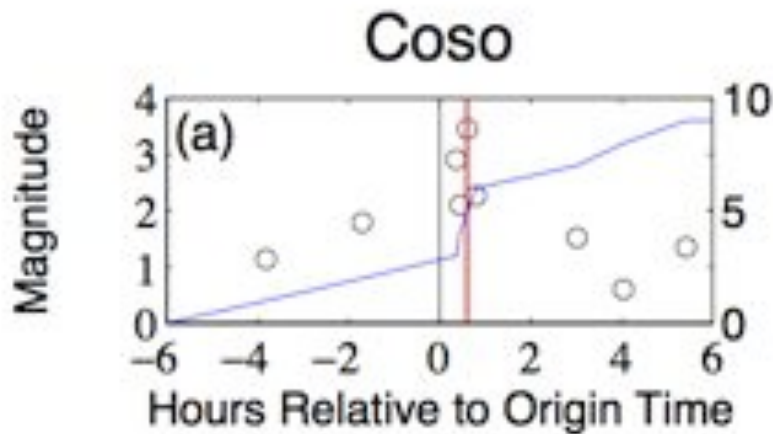
11/01/10

zpeng G

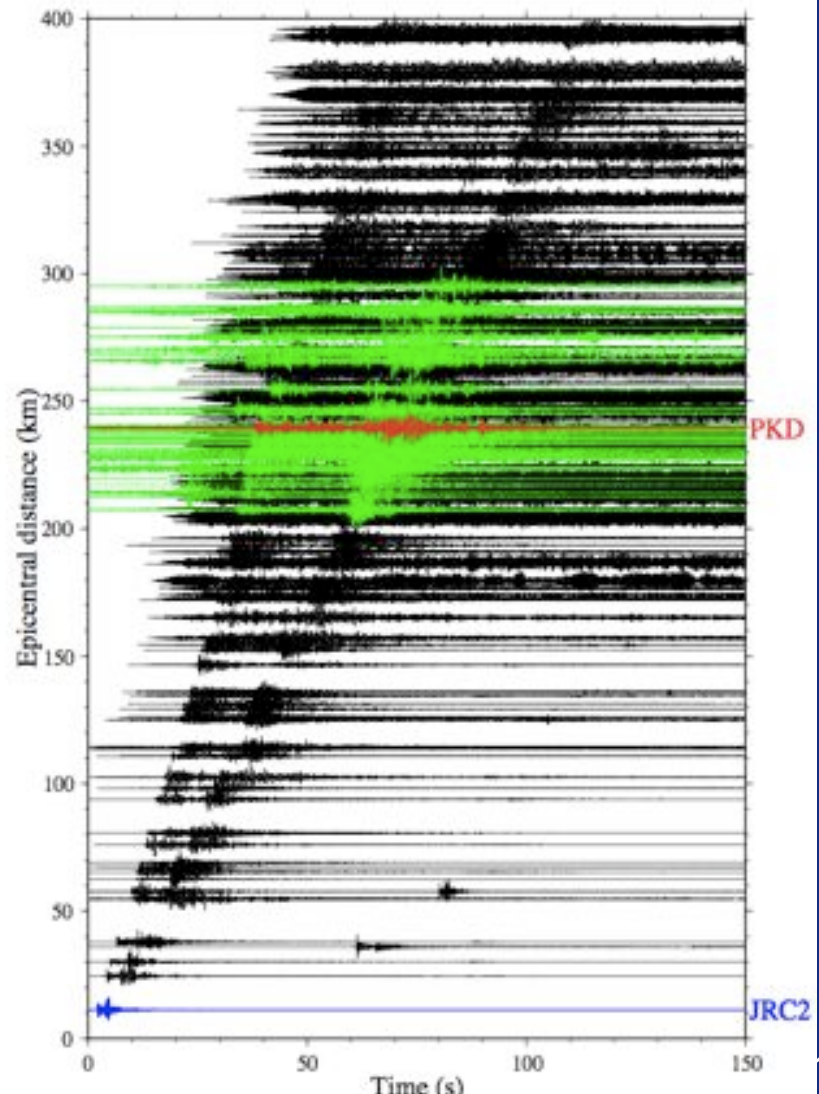
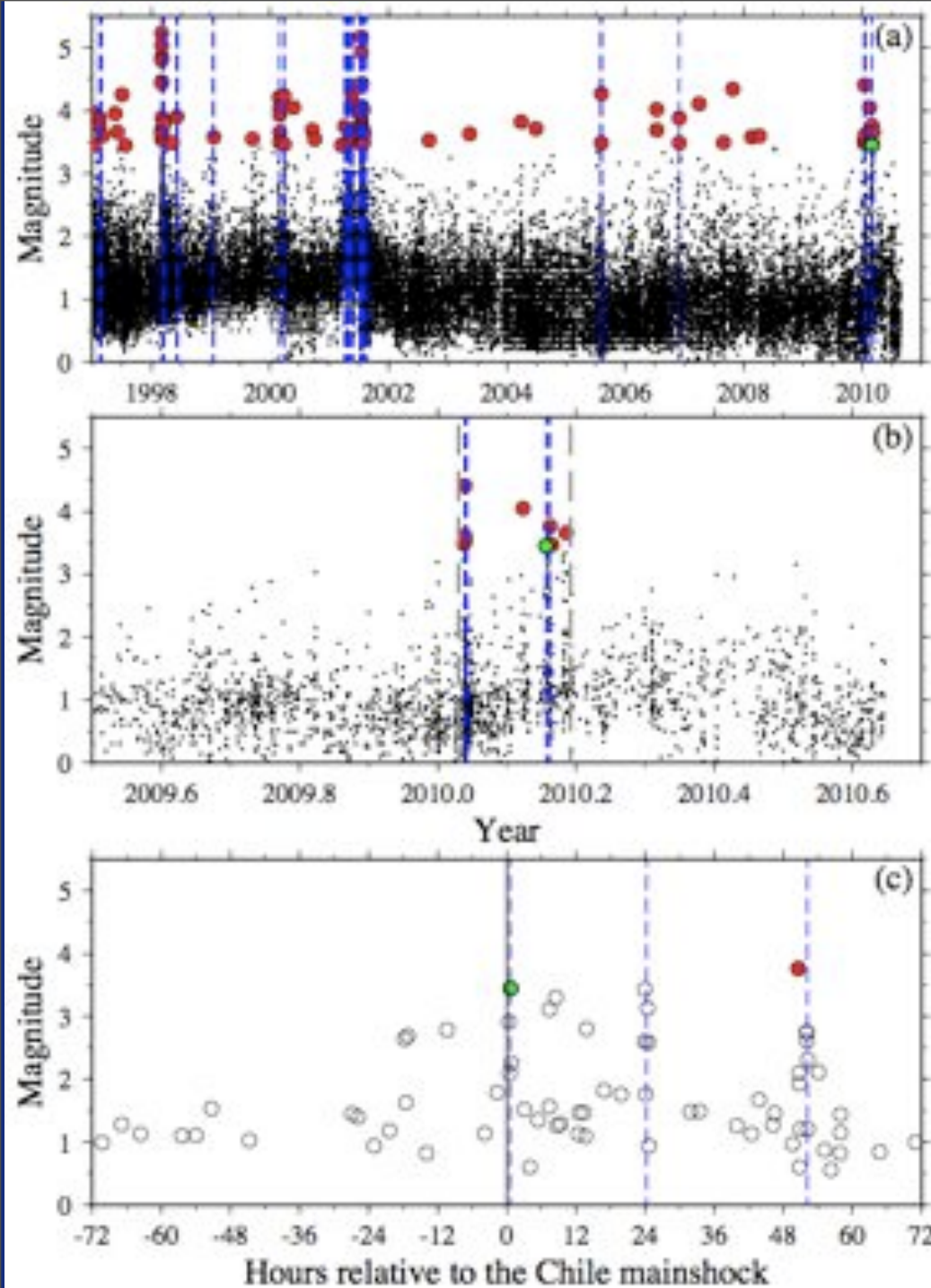
Monday, November 1, 2010

2010 Mw8.8 Chile Earthquake Triggers Low Frequency Earthquakes at Parkfield

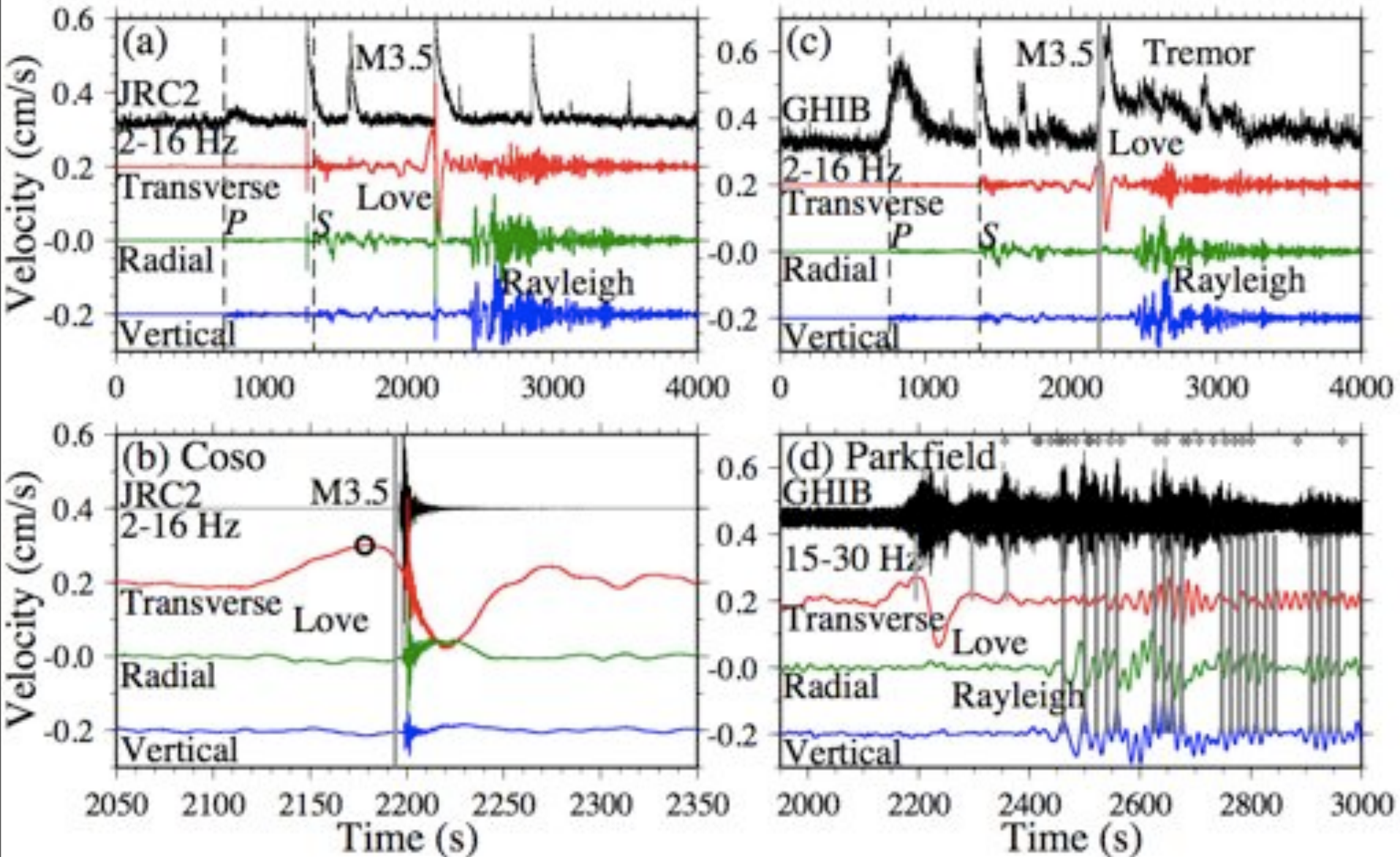




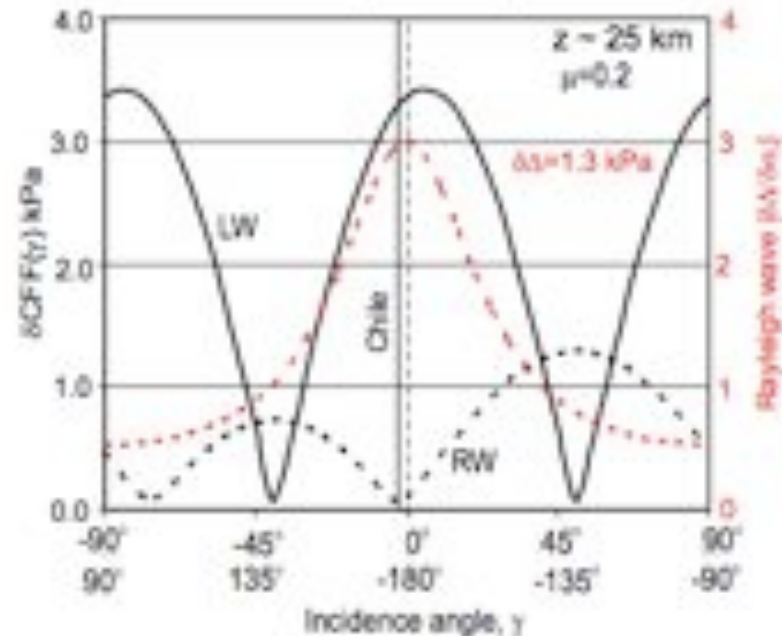
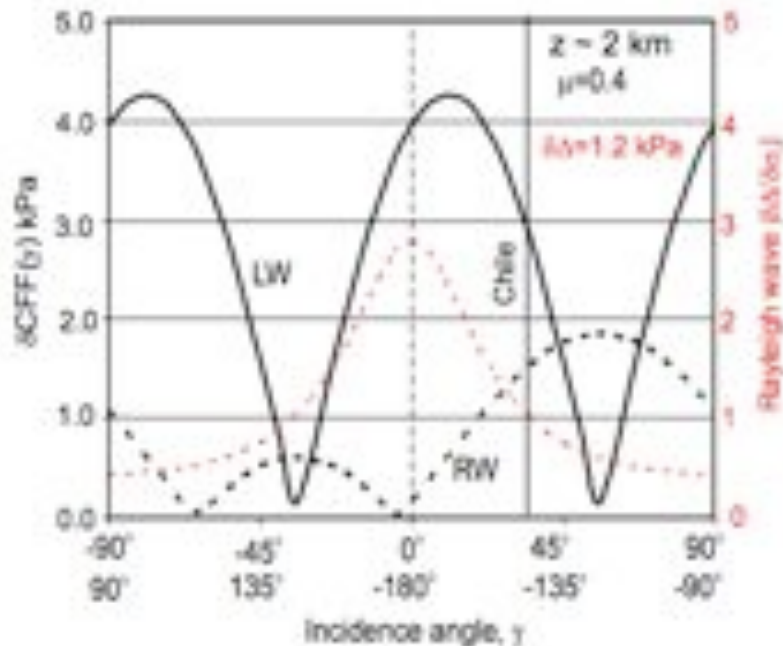
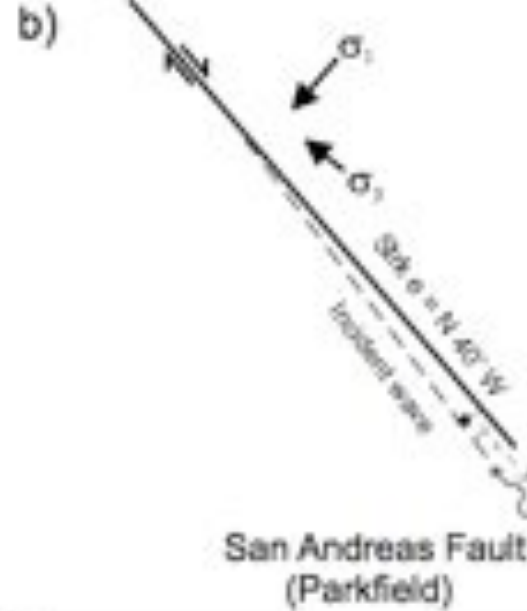
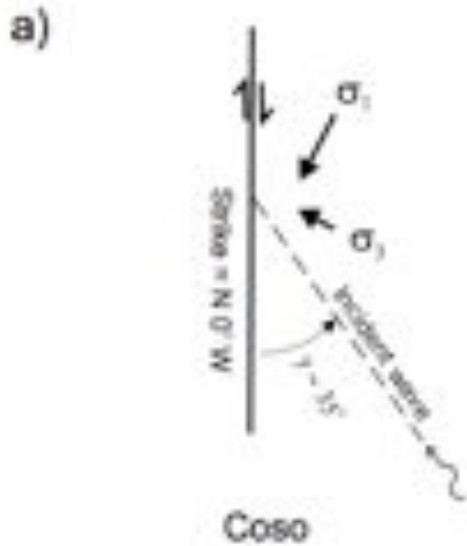
Probabilities of seeing a M3.5 or 4 M \geq 2 earthquakes in any given hour is less than 1%

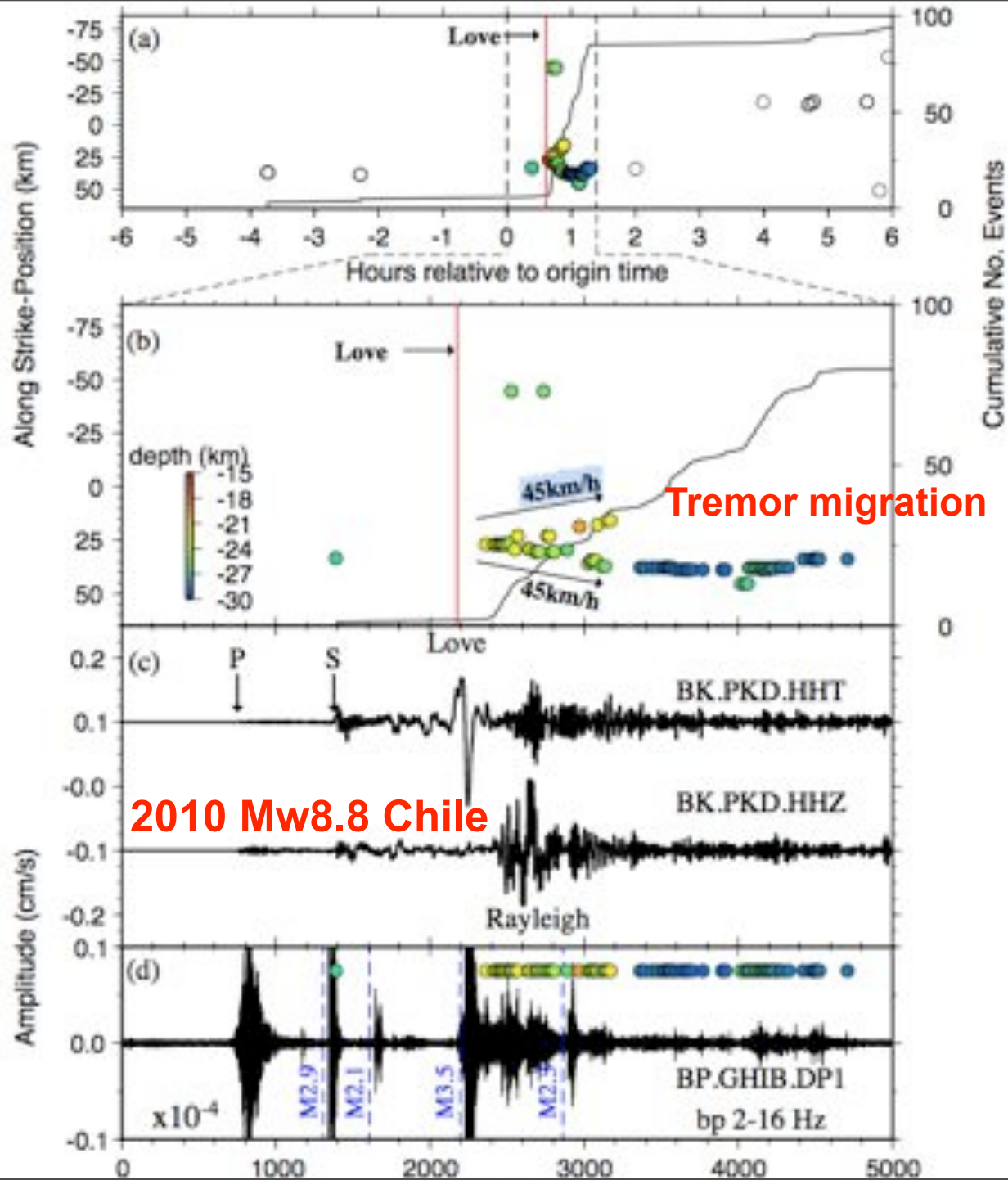


Comparisons between the surface waves and triggered activity

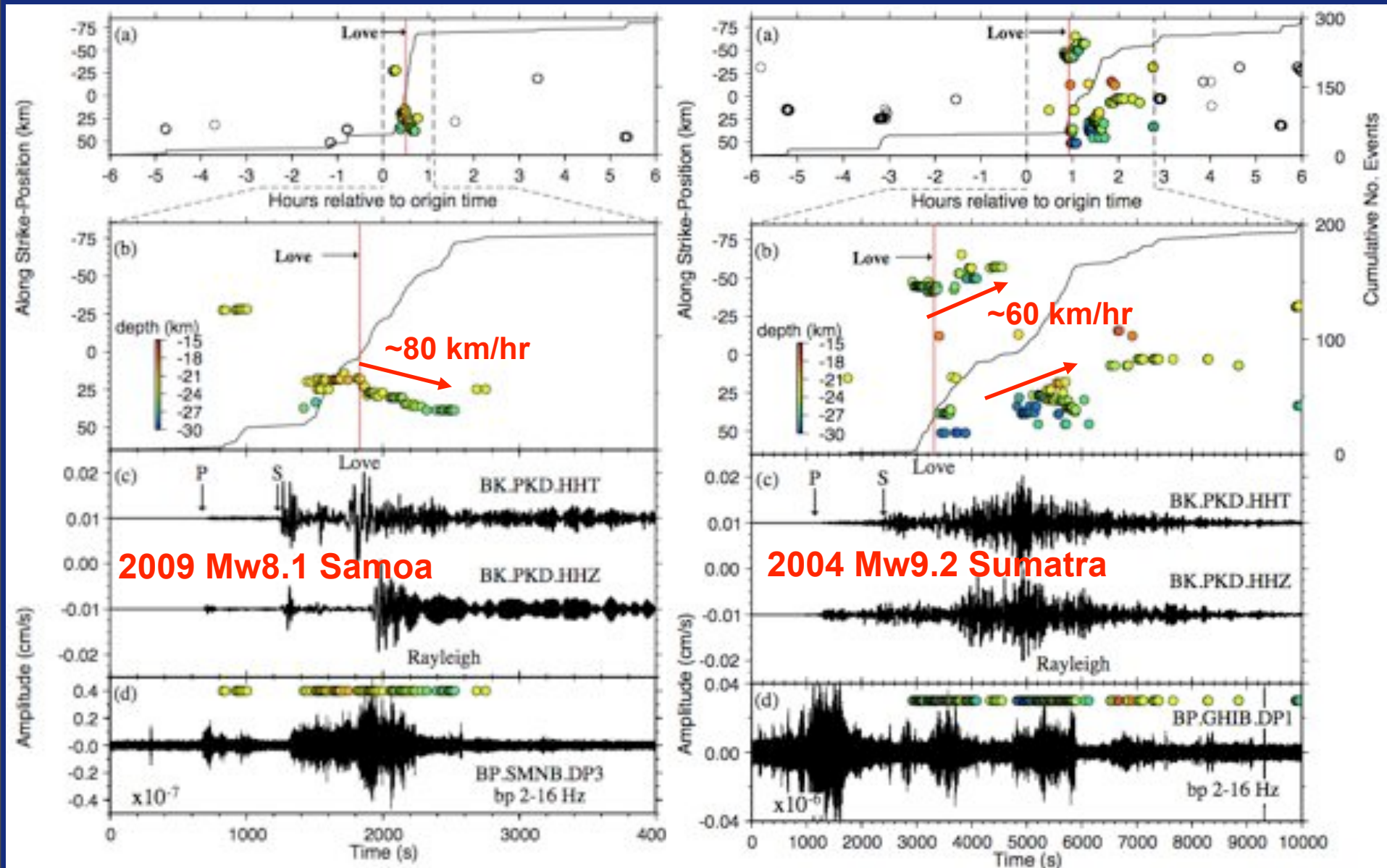


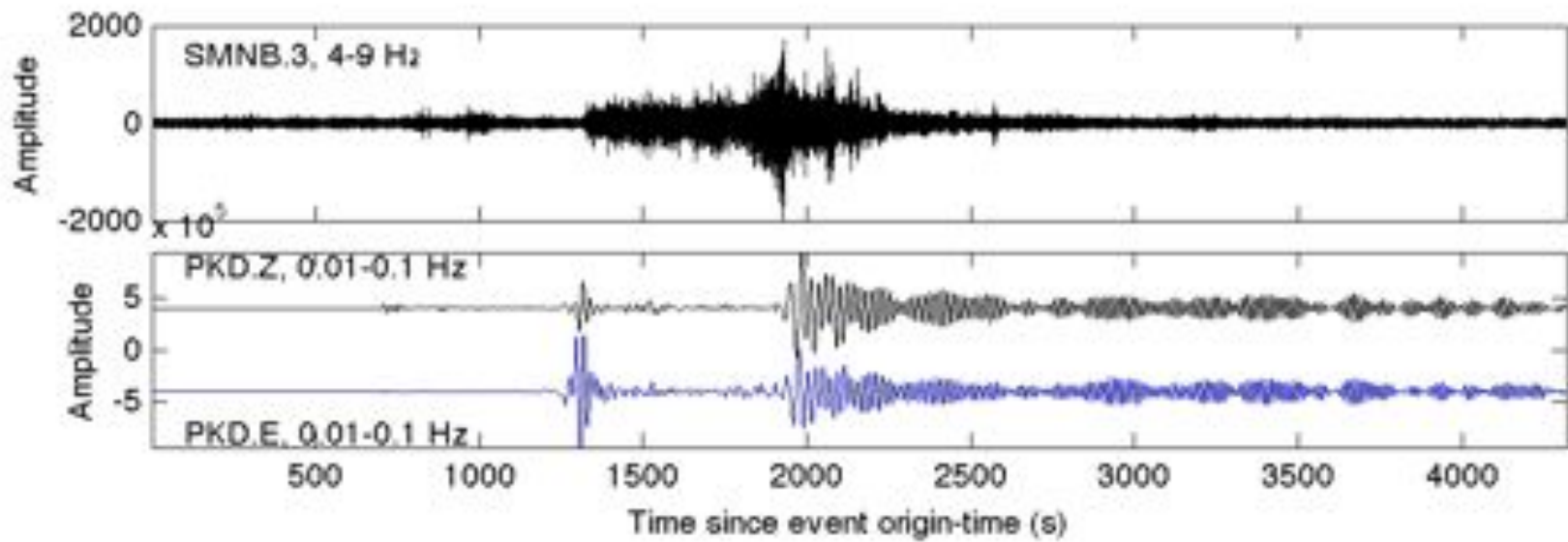
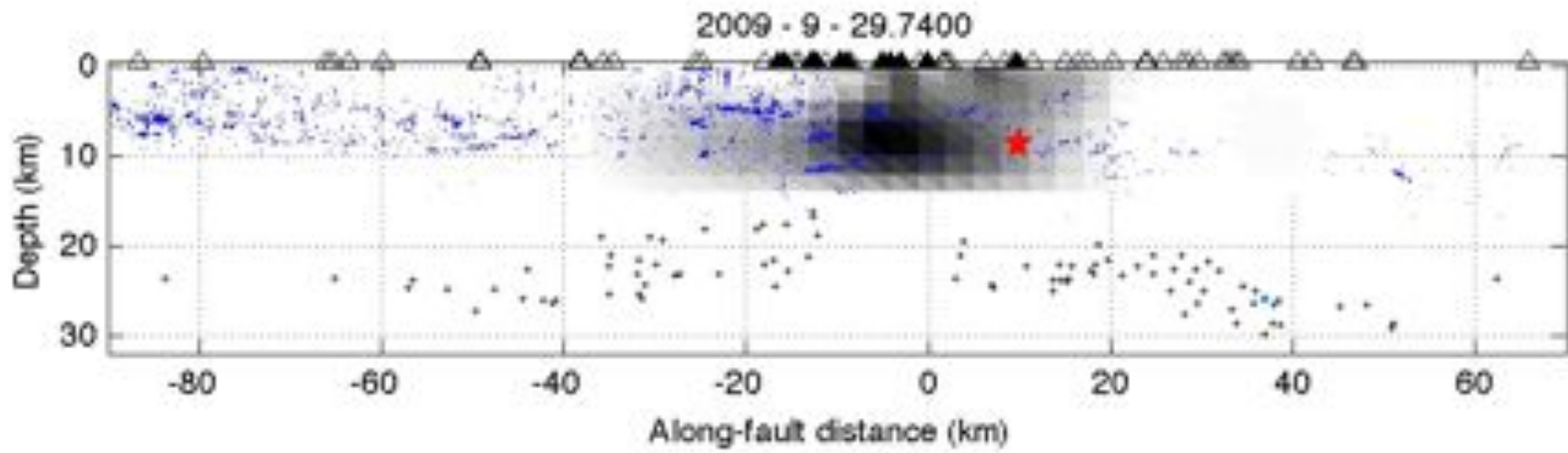
Triggering potential for Love and Rayleigh waves from Coulomb failure criterion (Hill, BSSA, 2008, 2010)





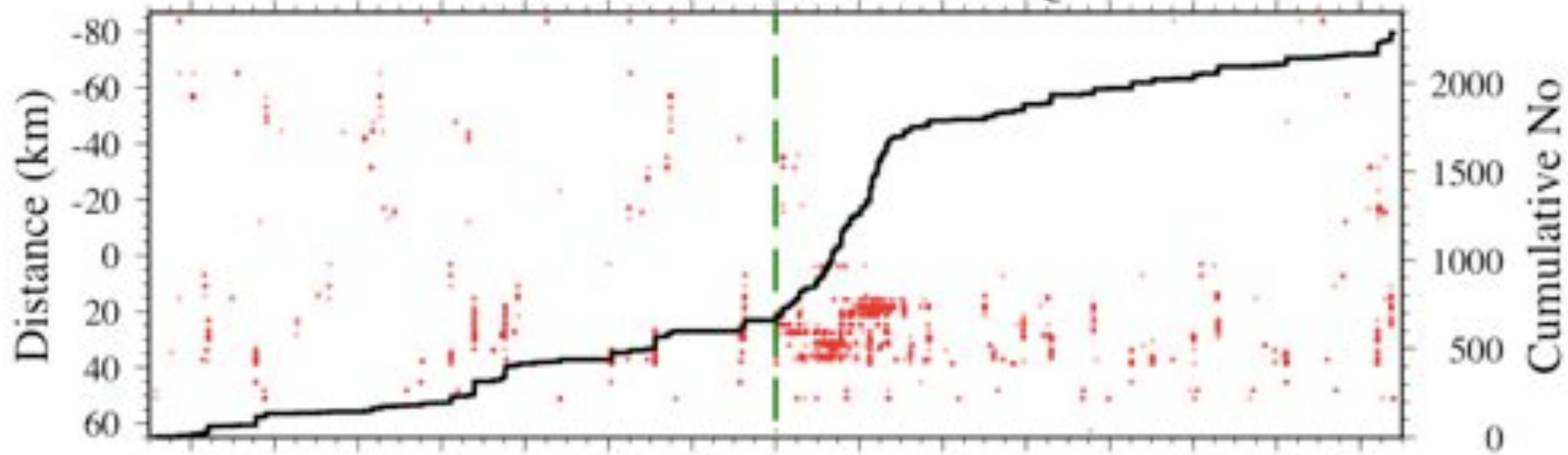
Triggered tremor migration triggered by the 2009 Mw8.1 Samoa and 2004 Mw9.2 Sumatra EQs (Shelly et al., submitted)



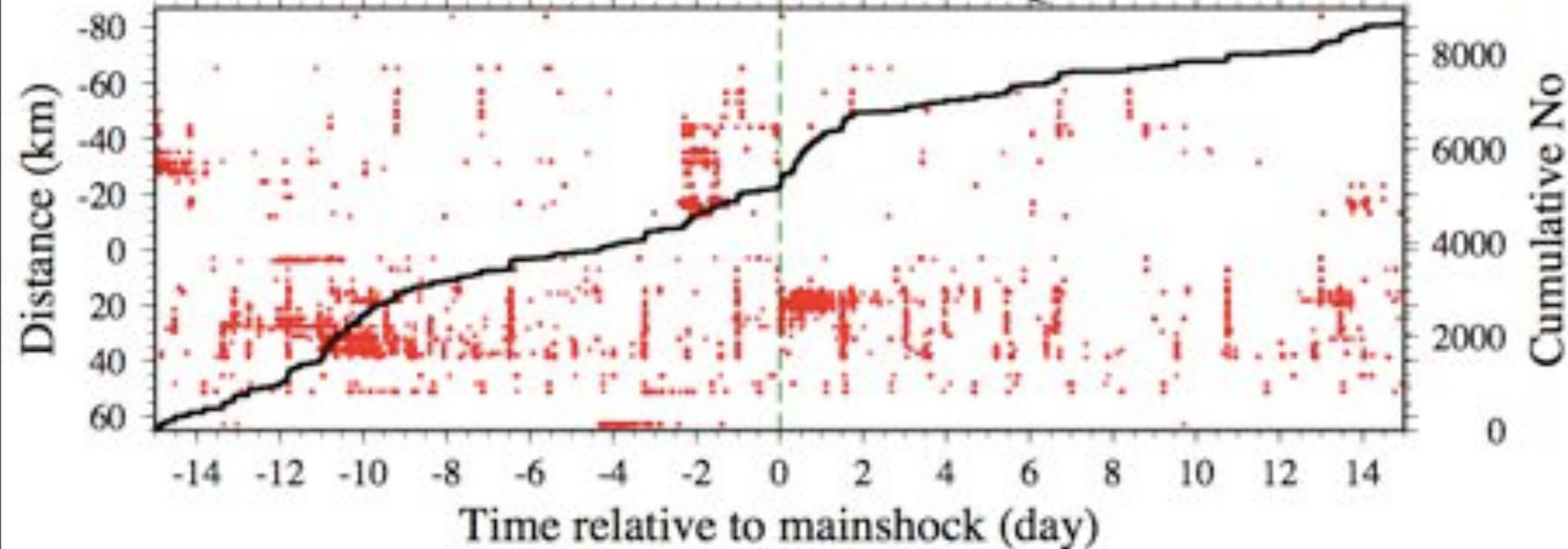


Delayed triggering of tremor after surface waves

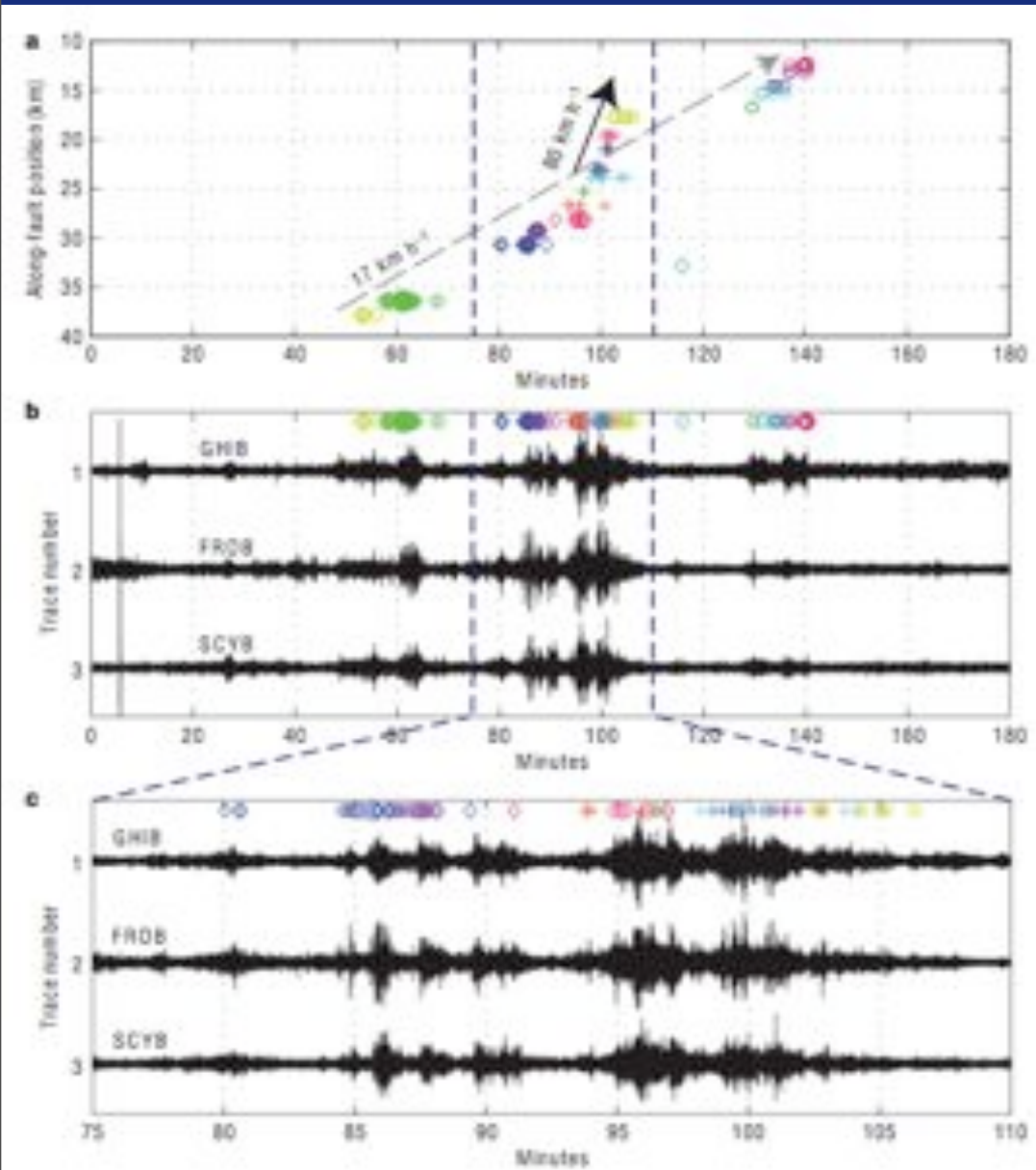
2002 Mw7.9 Denali Fault EQ



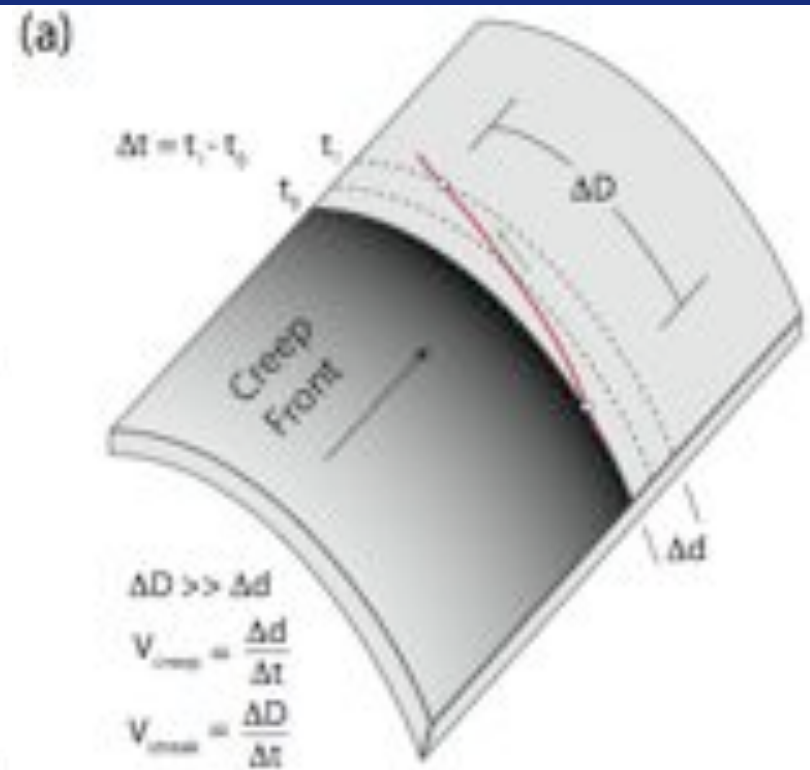
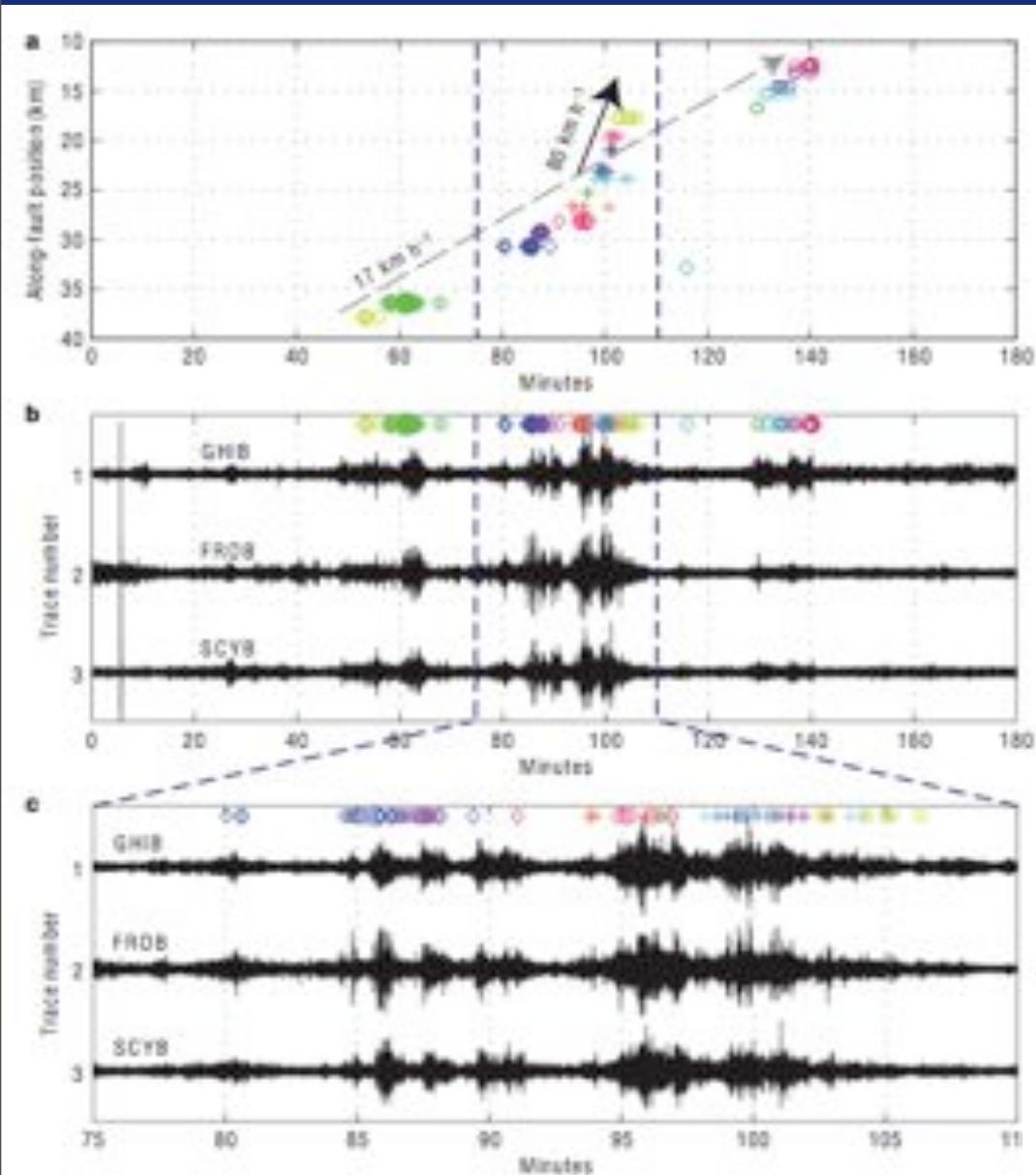
2008 Mw7.9 Wenchuan EQ



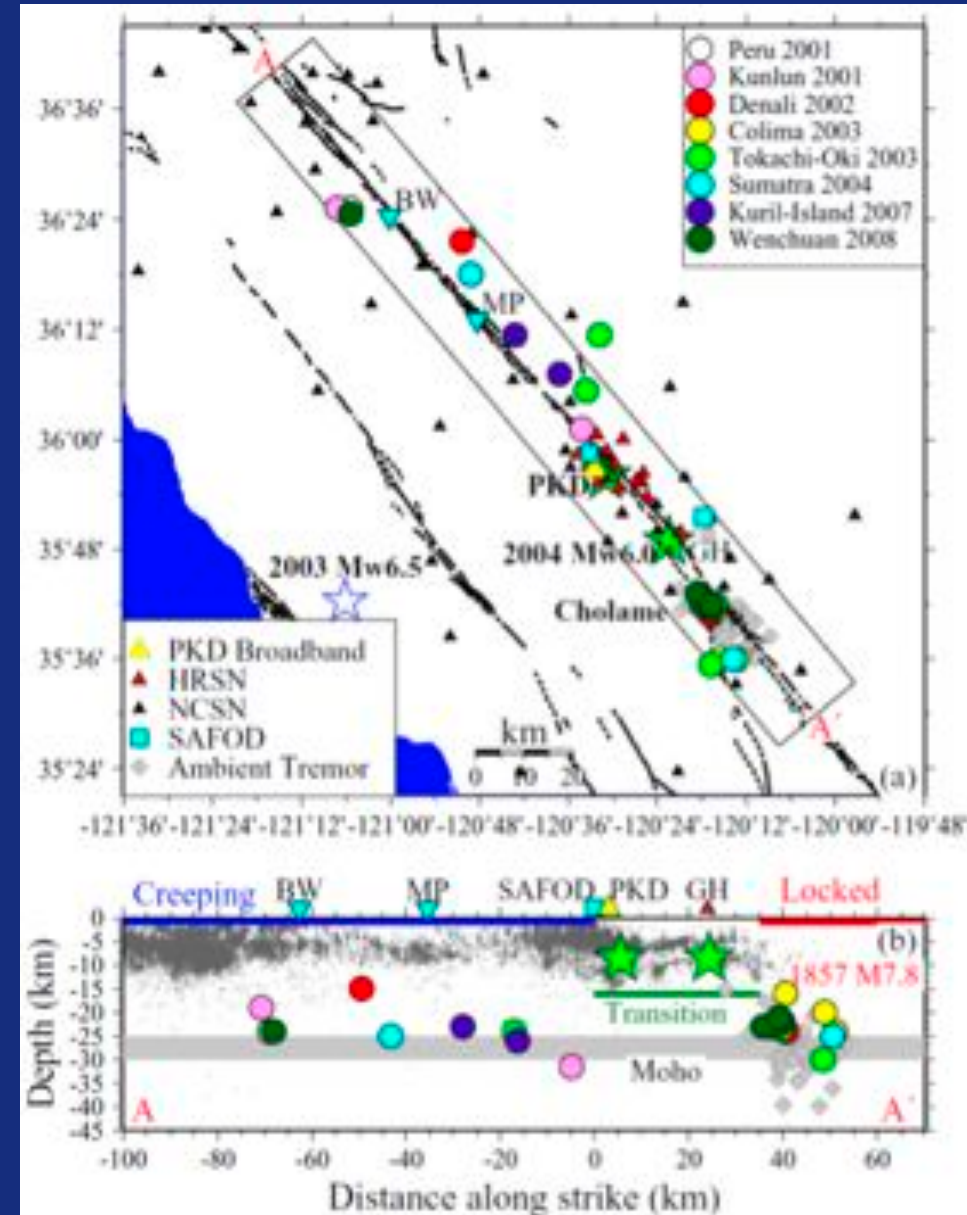
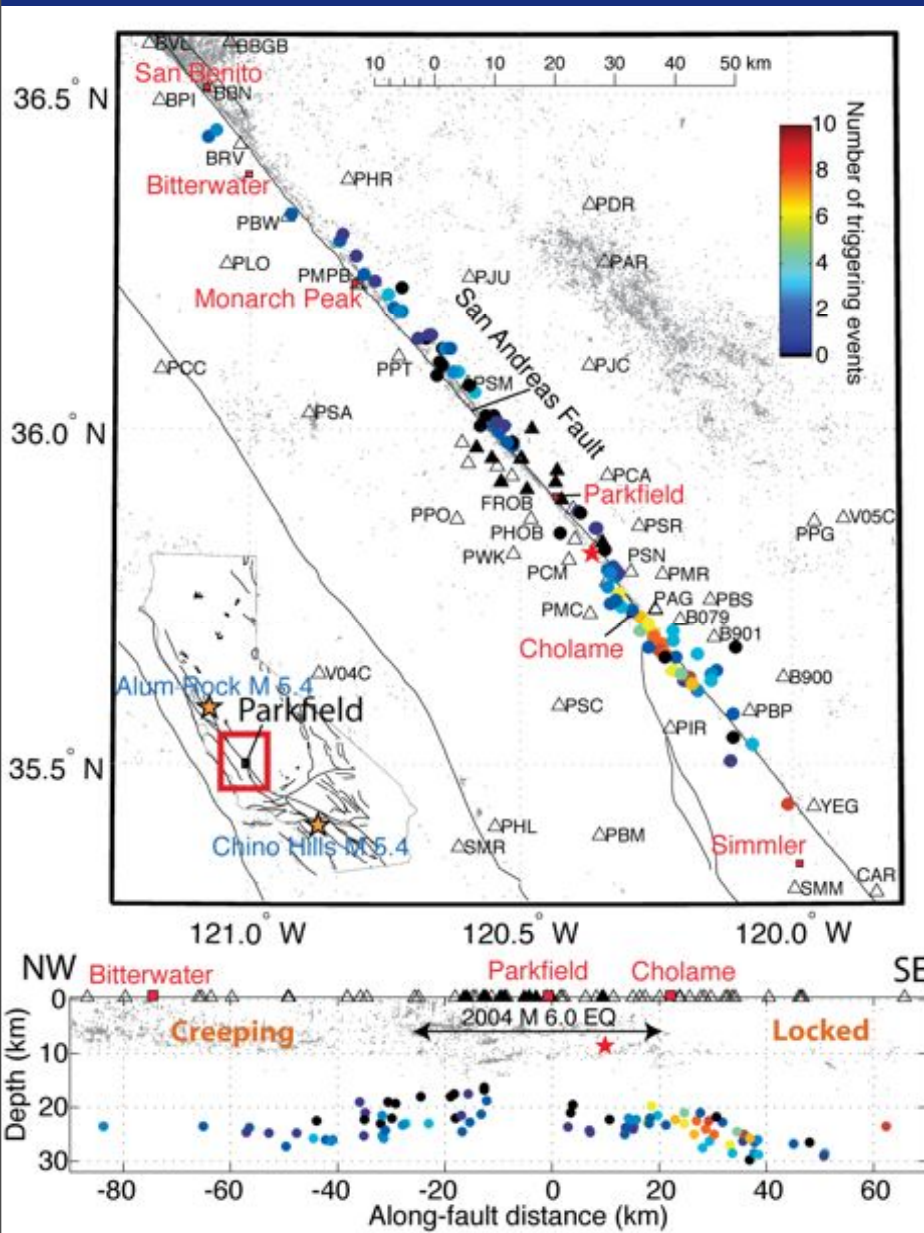
Ambient Tremor migration - deep slow-slip



Ambient Tremor migration - deep slow-slip



Most triggered low-frequency eqs were at Cholame



Shelly et al. (submitted)

Peng et al. (JGR, 2009)

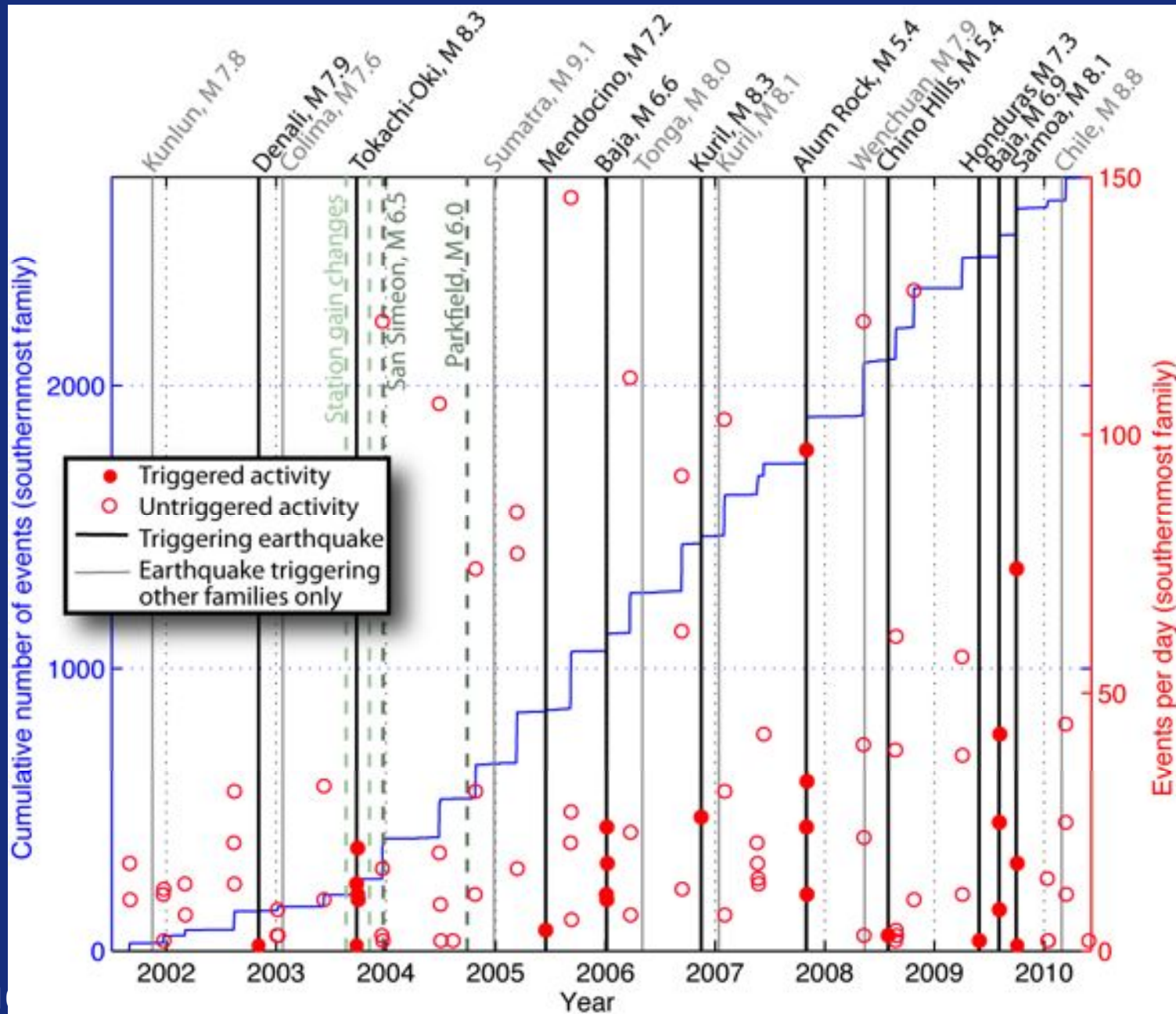
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Triggering activity in southernmost family

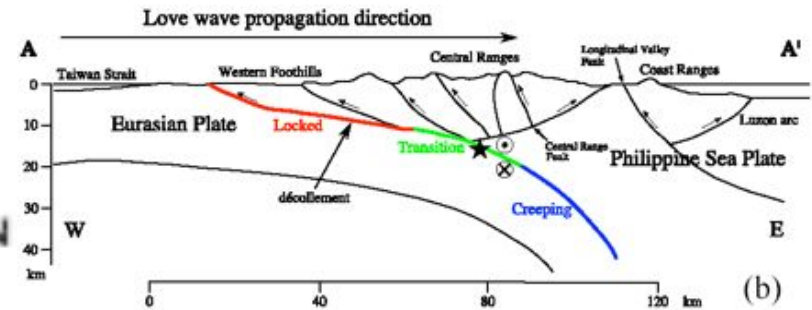
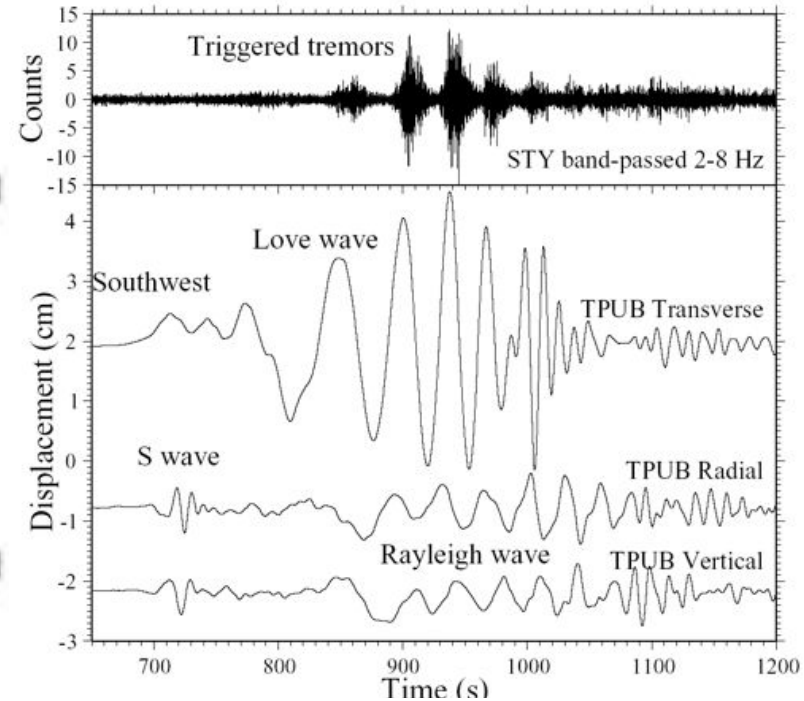
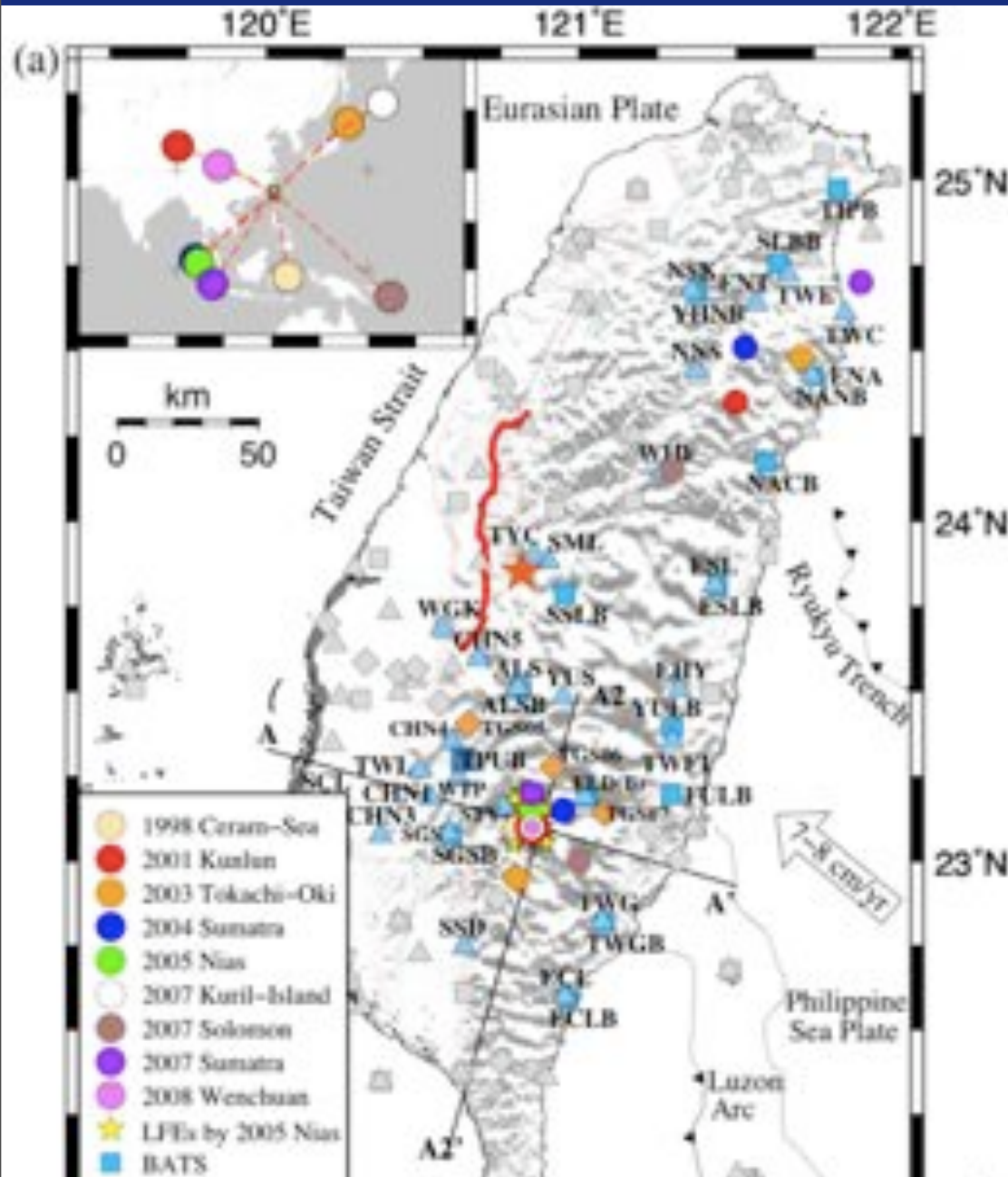




Summary I

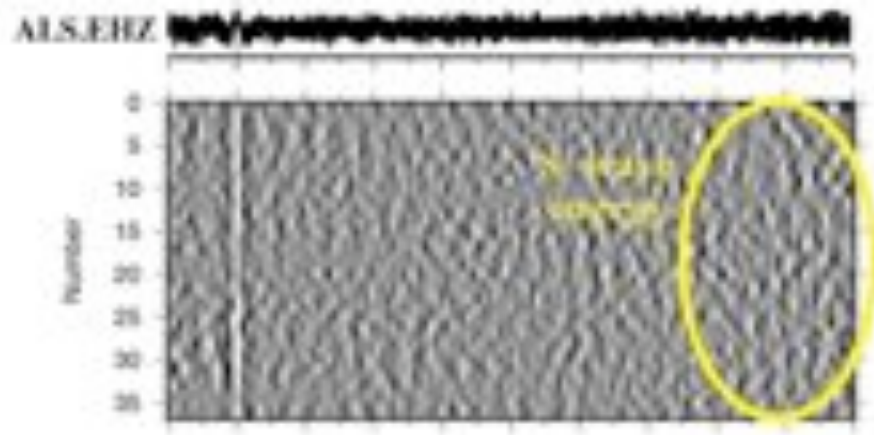
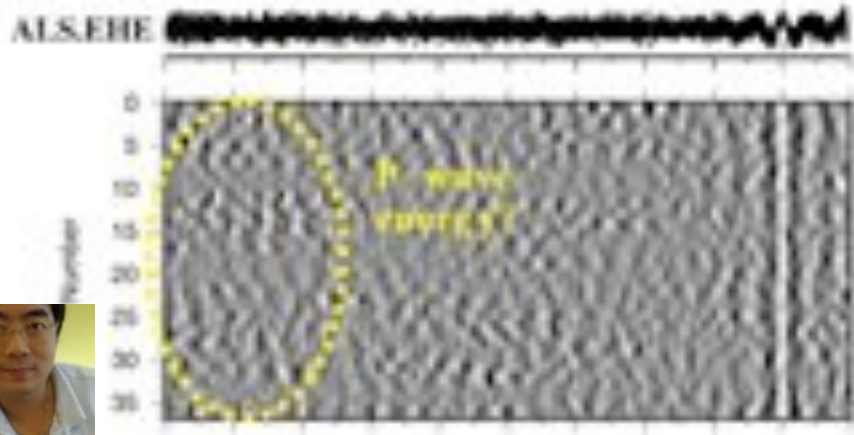
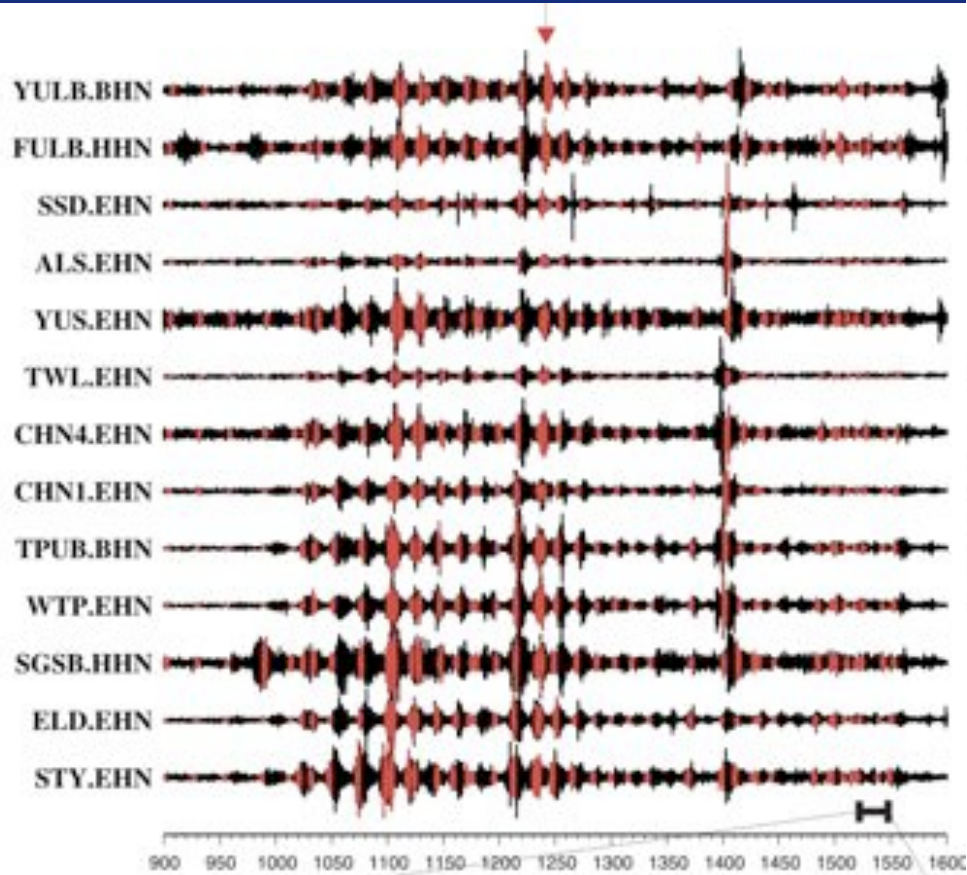
- Triggered and ambient tremor shares common sources (consisting of many low-frequency earthquakes) and a common physical mechanisms.
- Triggered earthquakes and tremor could be explained by the simple Coulomb failure criterion, although their timing with the surface waves are different.
- Some triggered tremor sequences show clear along-strike migrations, likely reflecting small triggered deep creep events.
- Some sequences have elevated tremor activities lasting a few days, similar to triggered earthquakes, perhaps indicating somewhat longer (and longer duration) slow-slip

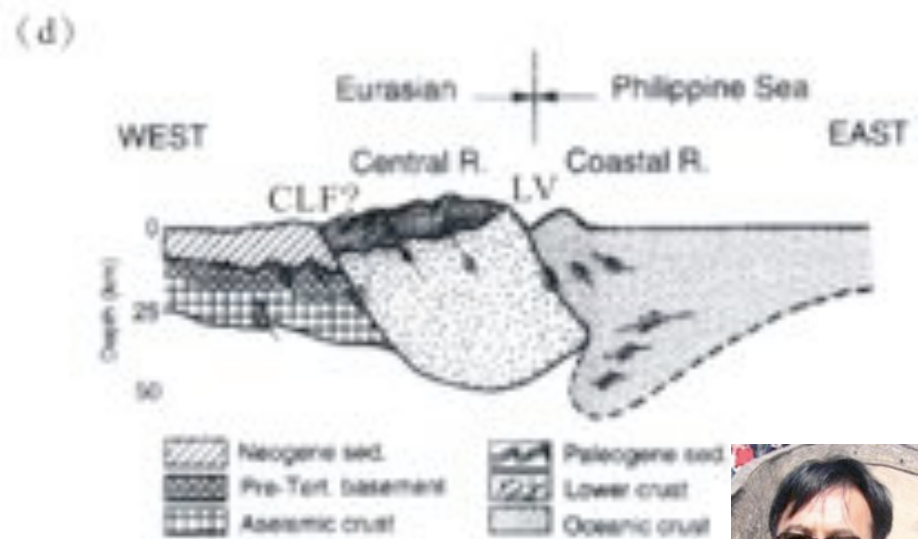
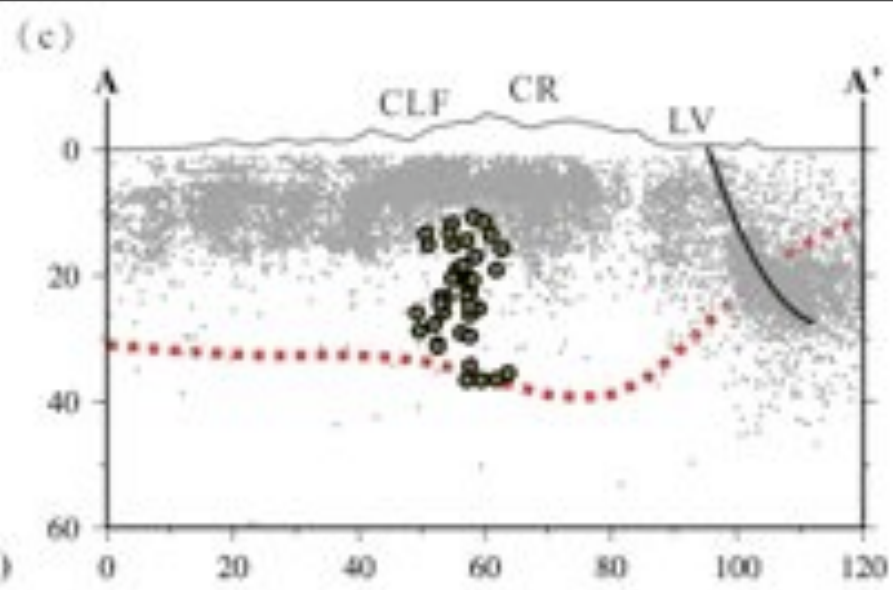
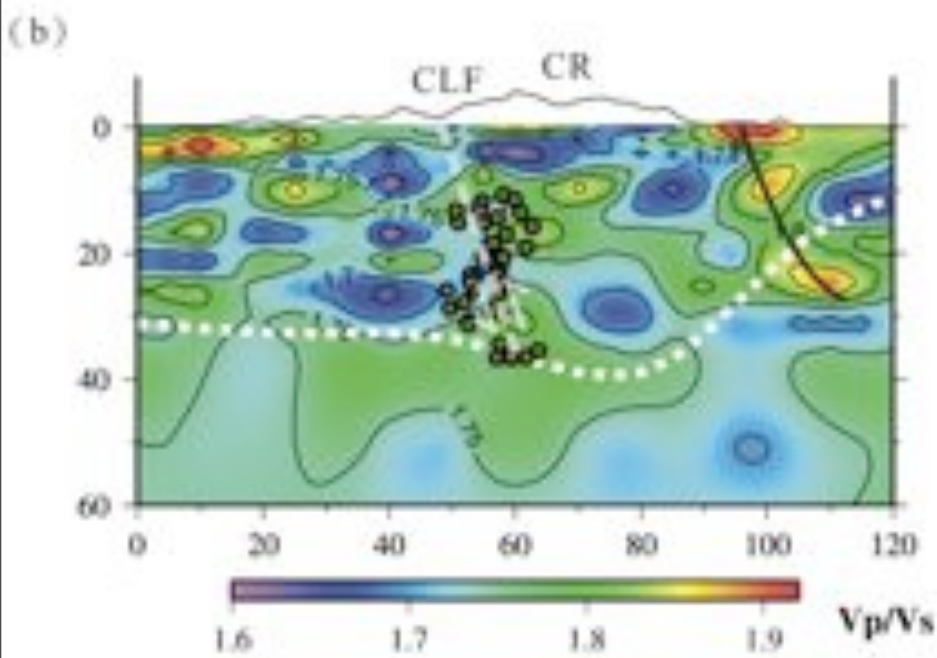
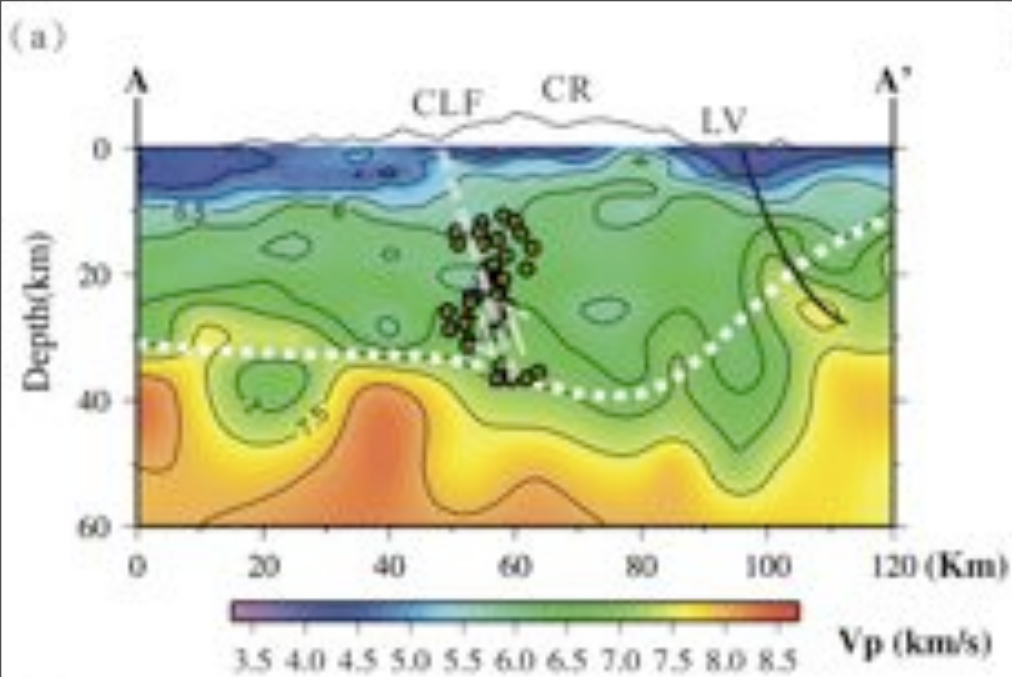
Triggered tremor in Taiwan



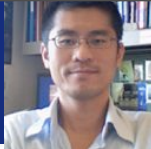
Tremor on the detachment beneath the central Range Peng and Chao (GJI, 2008)

Triggered LFEs (Tang et al., GRL, 2010)

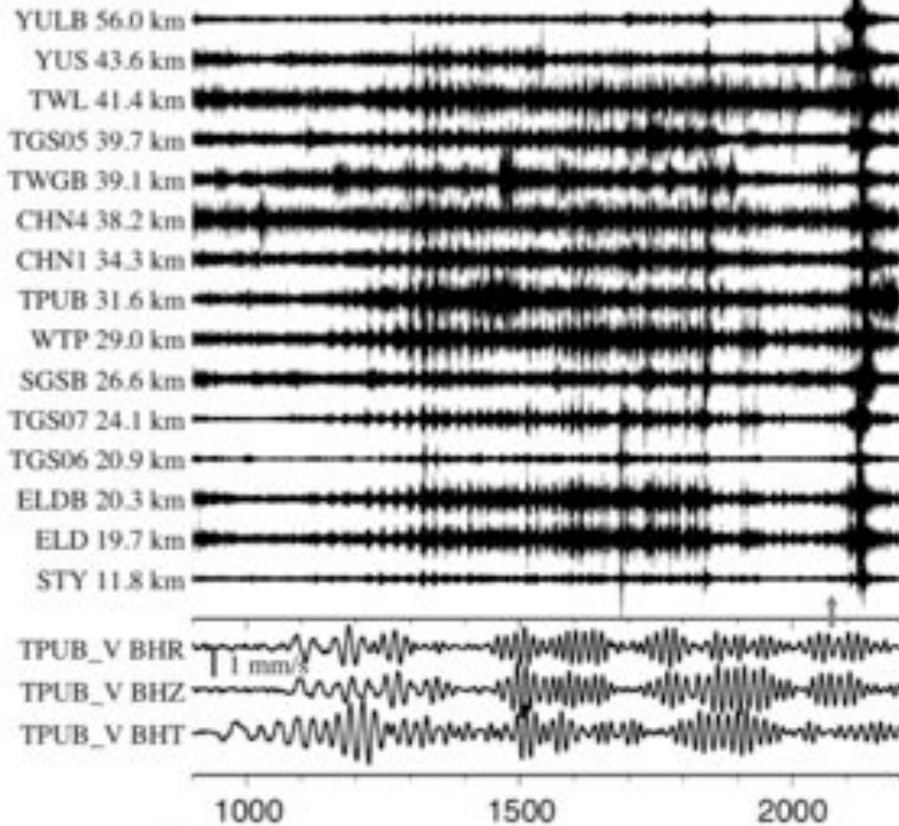




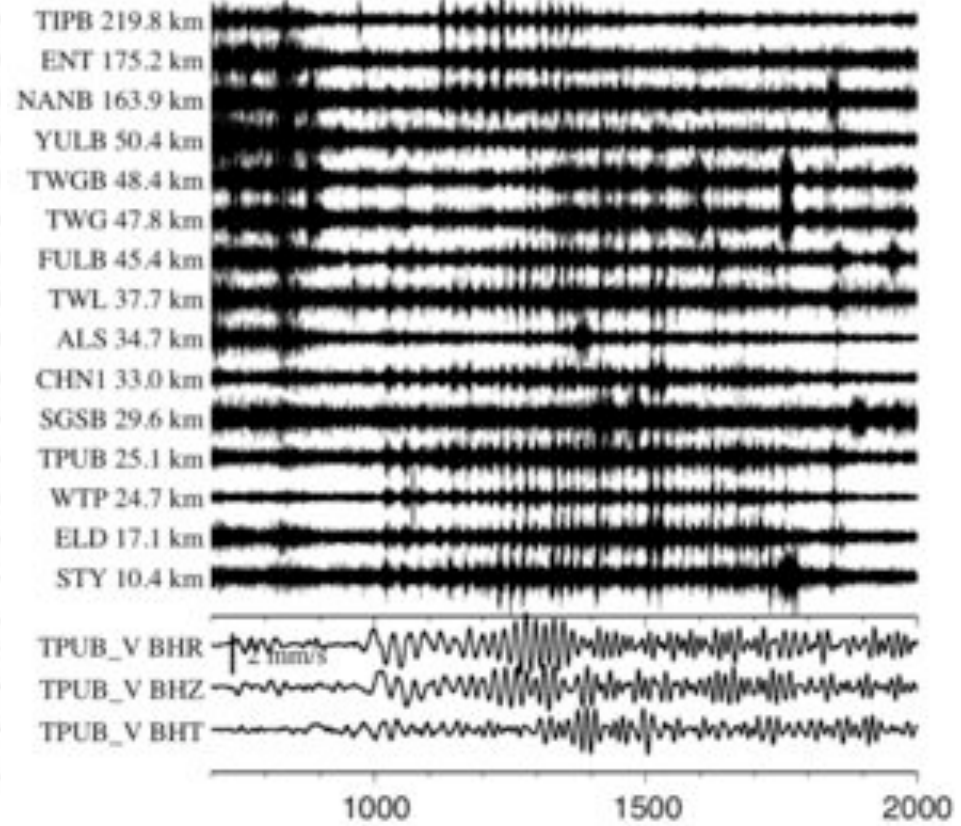
More triggered tremor observations in Taiwan (Chao et al., GJI, submitted)



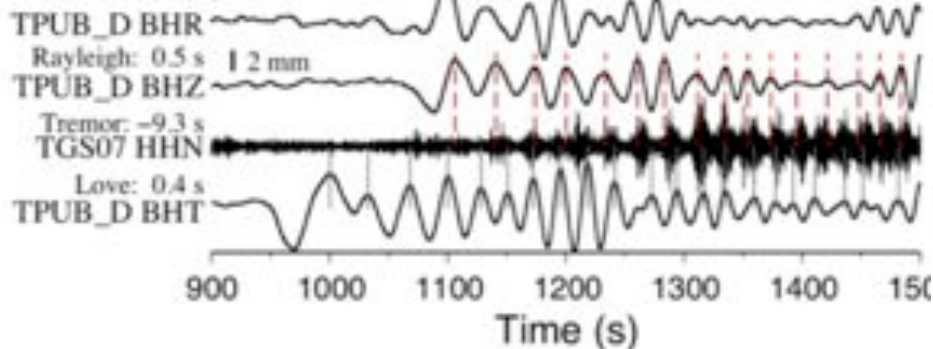
(a) 20070113: M 8.10, Dist 3961.6 km, BAZ 41°



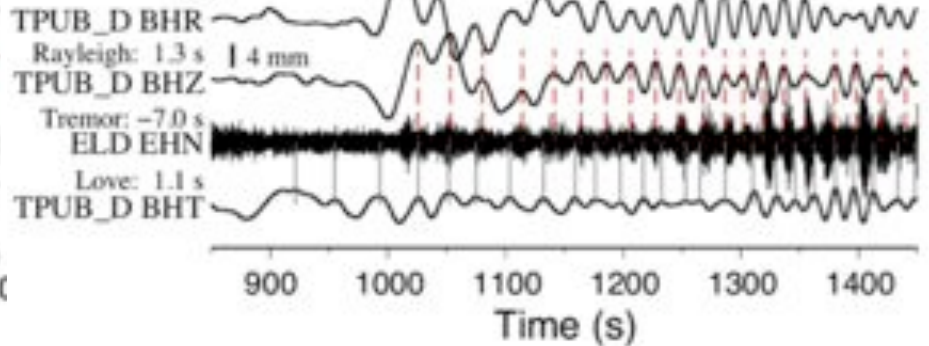
(a) 20070912: M 8.40, Dist 3710.6 km, BAZ 216°



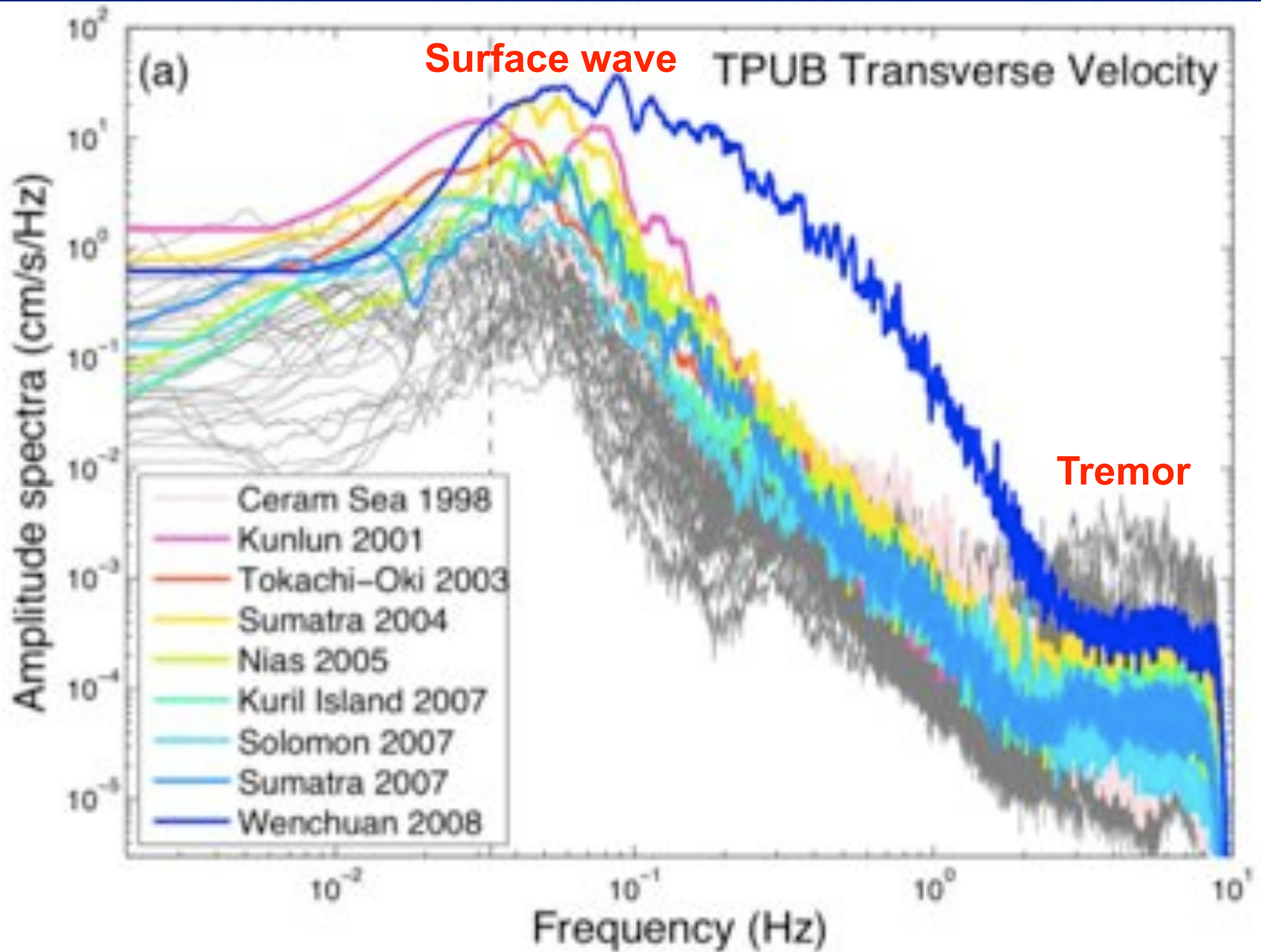
(b)



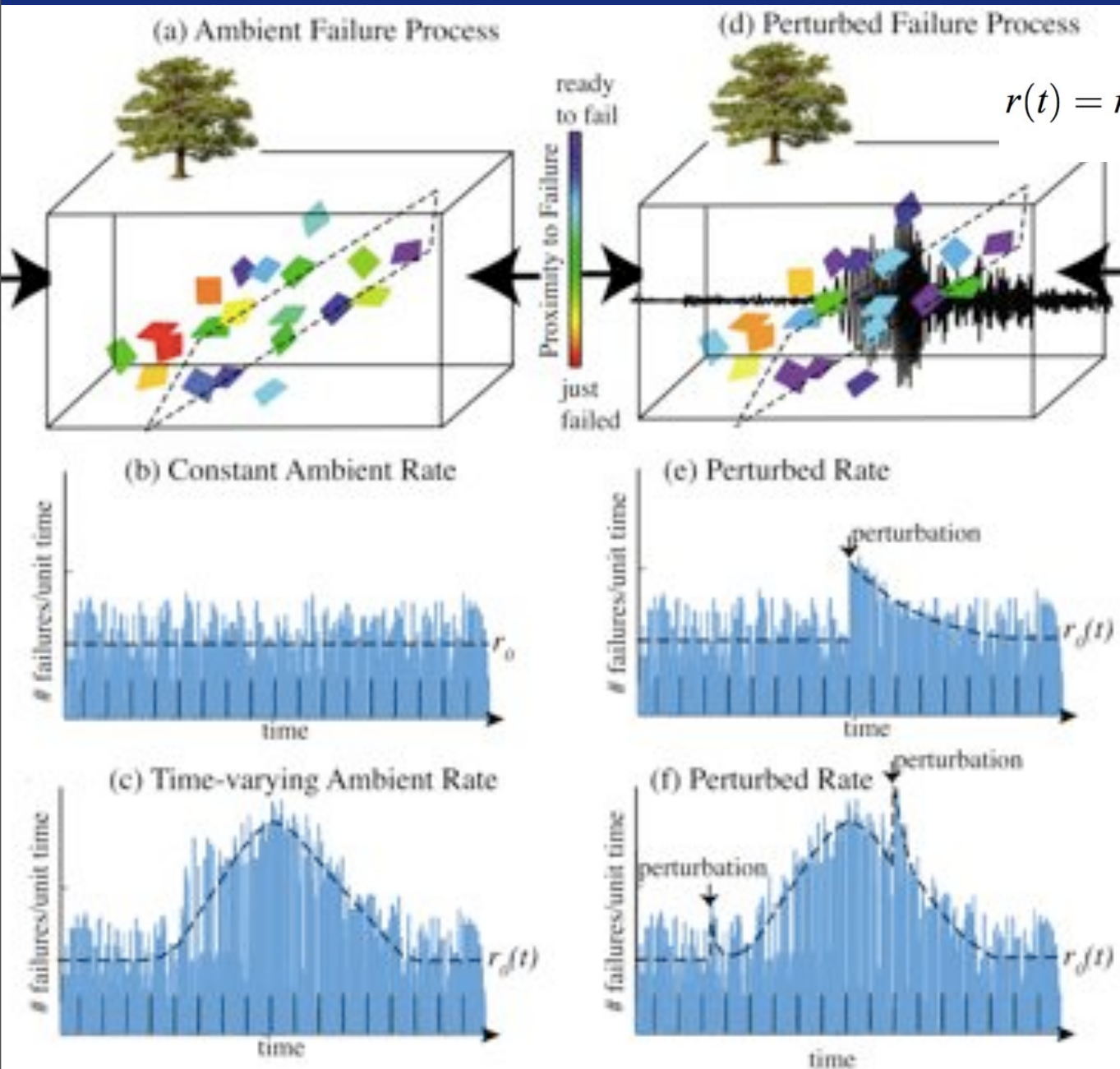
(b)



Frequency dependence of triggering potential



Cartoon of tremor and the clock-advanced model (Gomberg, JGR, 2010)

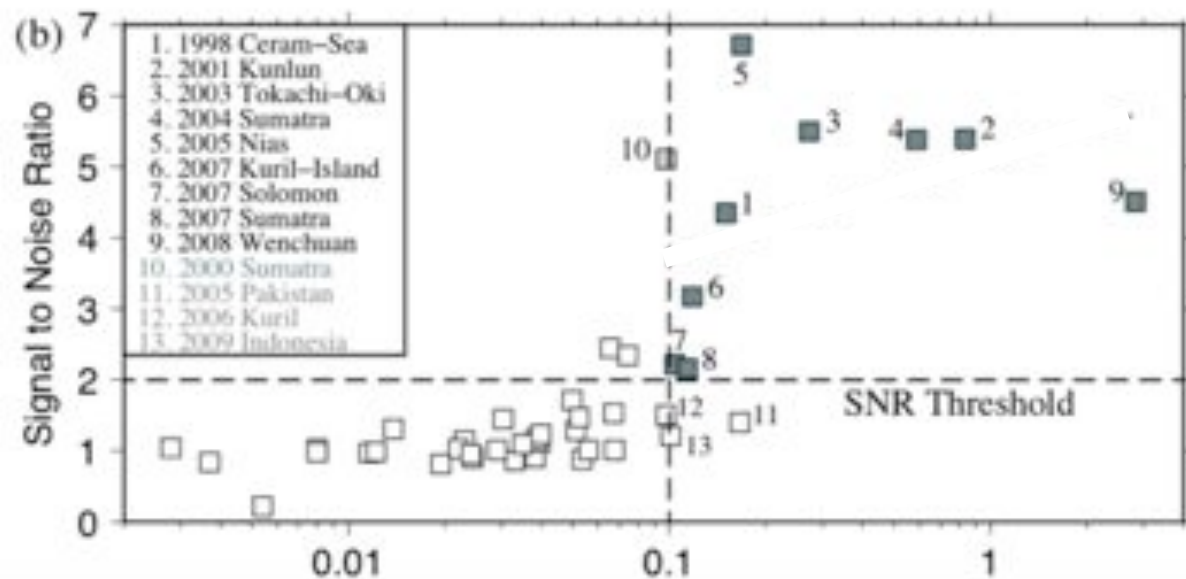
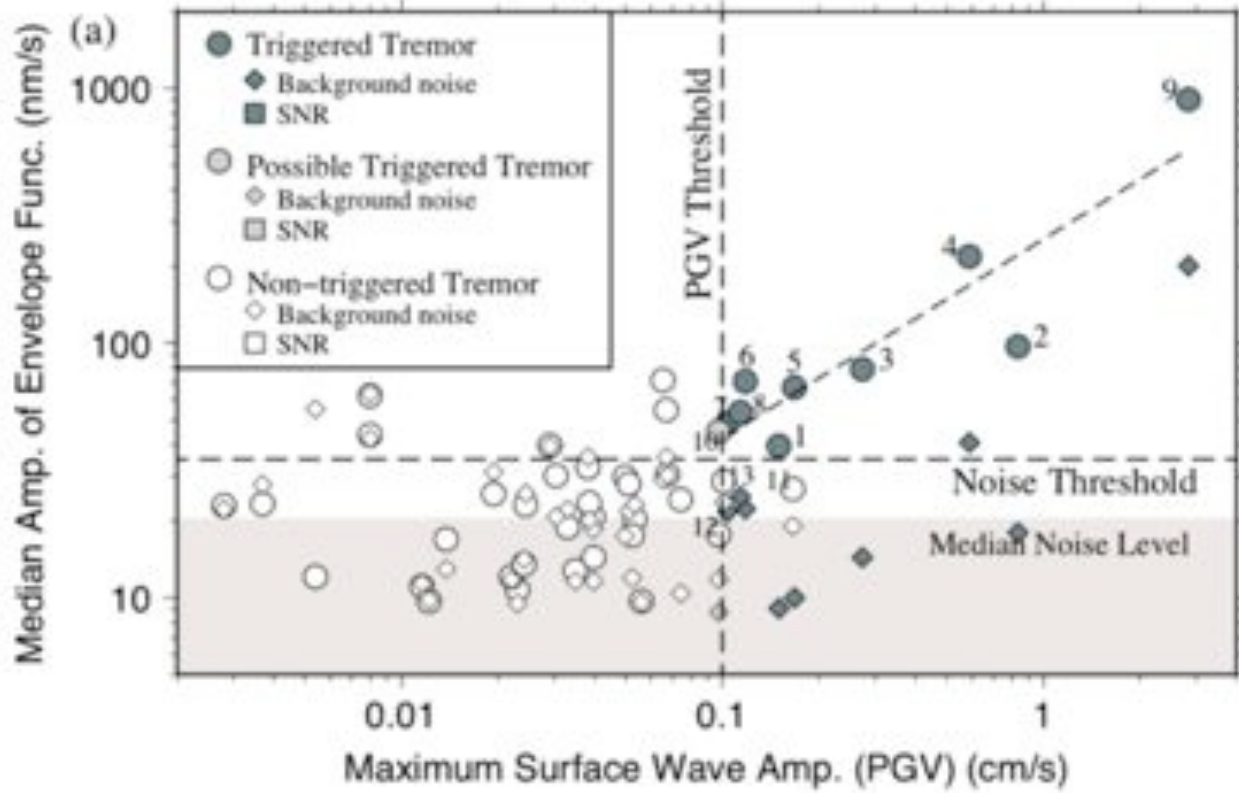


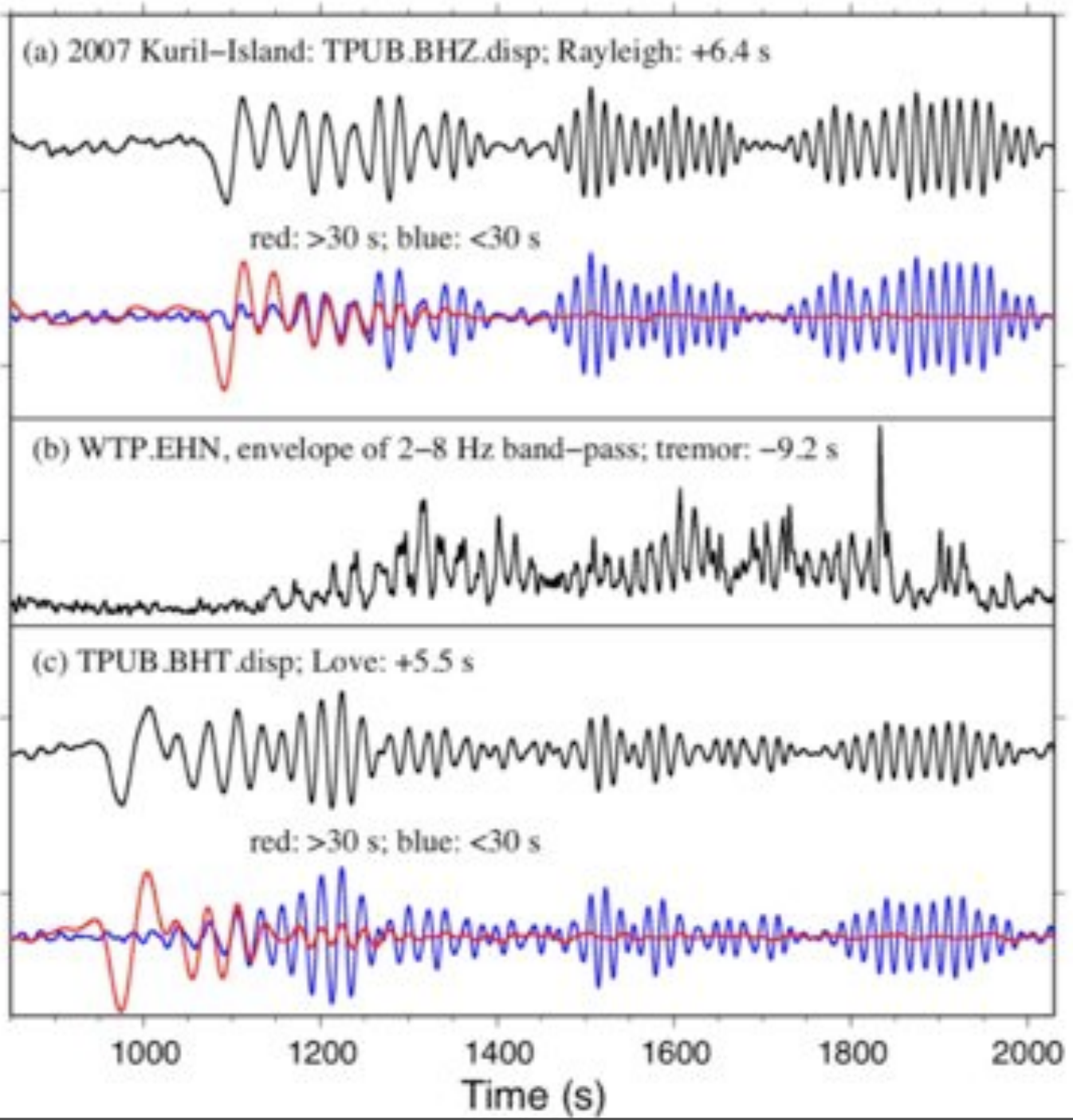
$$r(t) = r_0(t - \Delta t) \times \left[1 - \frac{d\Delta t}{dT}(t) \right]^{-1}$$

A greater ambient rate would correspond to higher likelihood of triggering.

Larger triggering waves would result in larger triggered tremor signals.







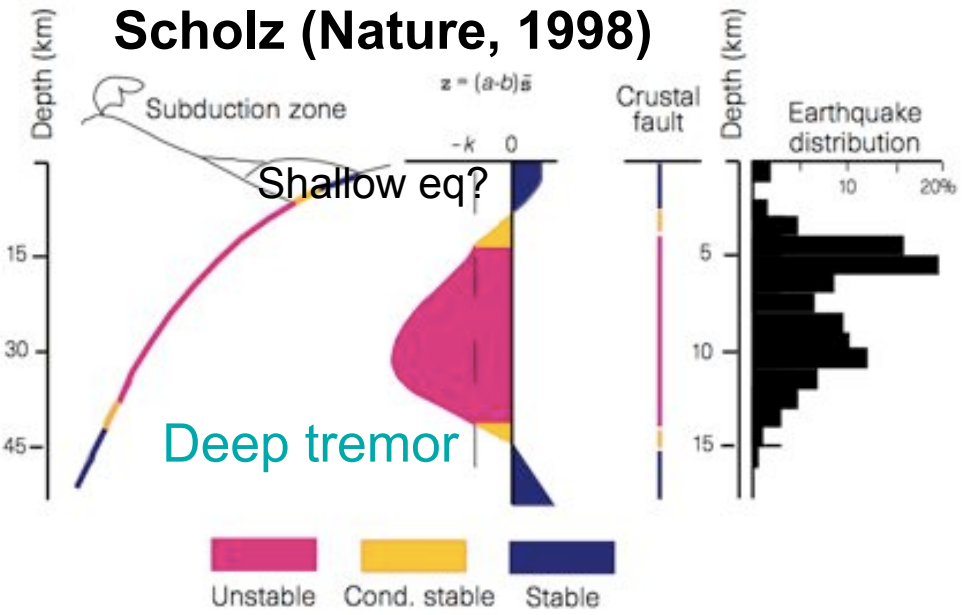
- New observations:
1. Long-period Love waves did not trigger any tremor.
 2. Tremor started 1-2 cycles after the Long-period Rayleigh waves.
 3. Tremor continues during the high-frequency (<30 s) surface waves, and the tremor amplitudes does not correlate well with the surface wave amplitudes.



Summary II

- Triggered tremor in Taiwan also appear to be consisted of many low-frequency earthquakes, and may occur on a more vertical dipping faults rather than the shallow detachment fault.
- The triggering potential depends largely on the amplitude of the surface waves, and less on the incidence angle and the frequency content.
- Surface waves with larger amplitudes appear to trigger tremor with larger amplitude,

Scholz (Nature, 1998)



Dynamic triggering of shallow earthquakes in Beijing (Wu et al., GJI, submitted)



Triggered seismicity are extremely shallow (<3 km) and do not correlate with background seismicity
Shallow creep observed at times

