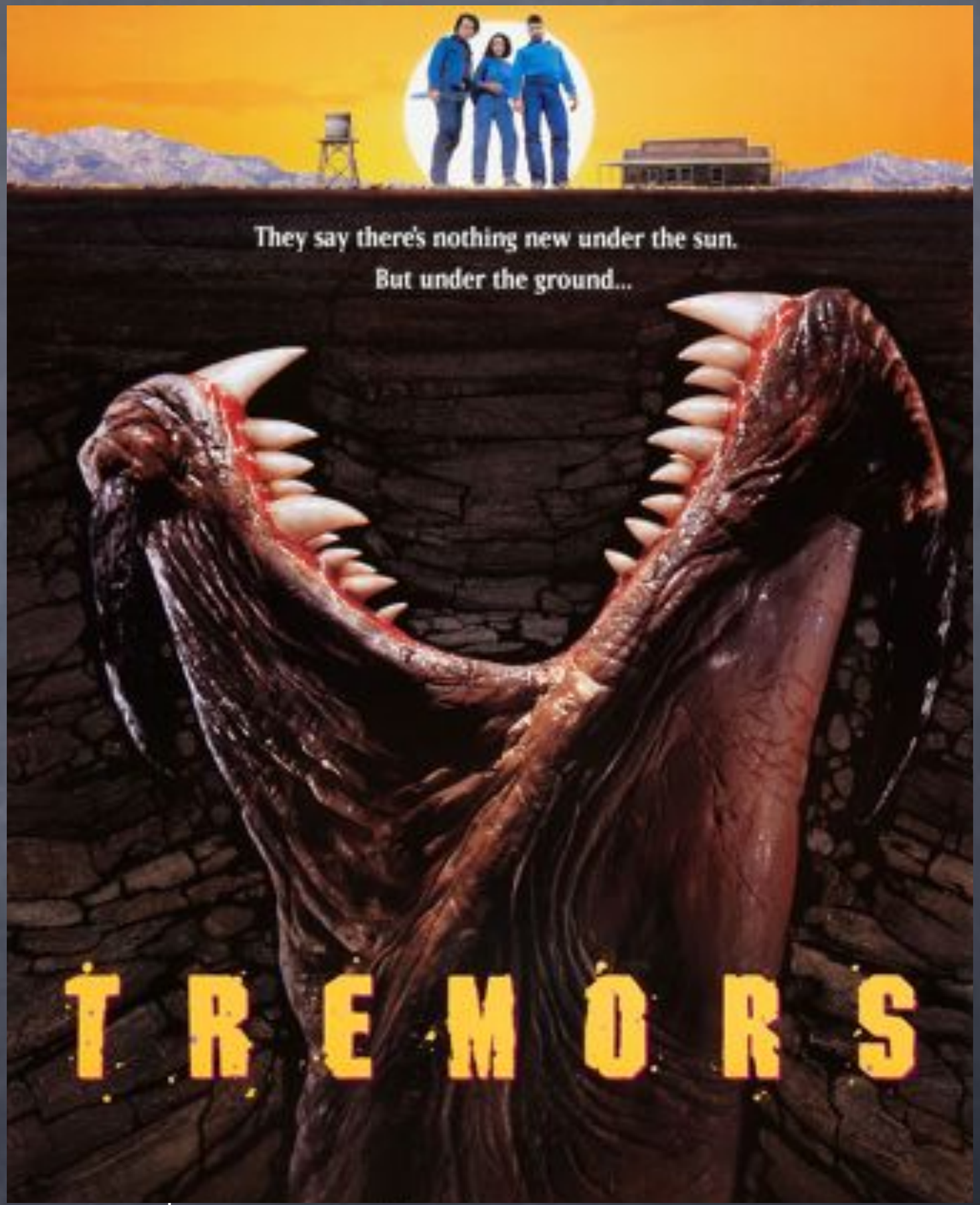
The mystery of fault tremor; where, when, how, and why?

mostly review

Earthscope Institute on the spectrum of fault slip behaviors

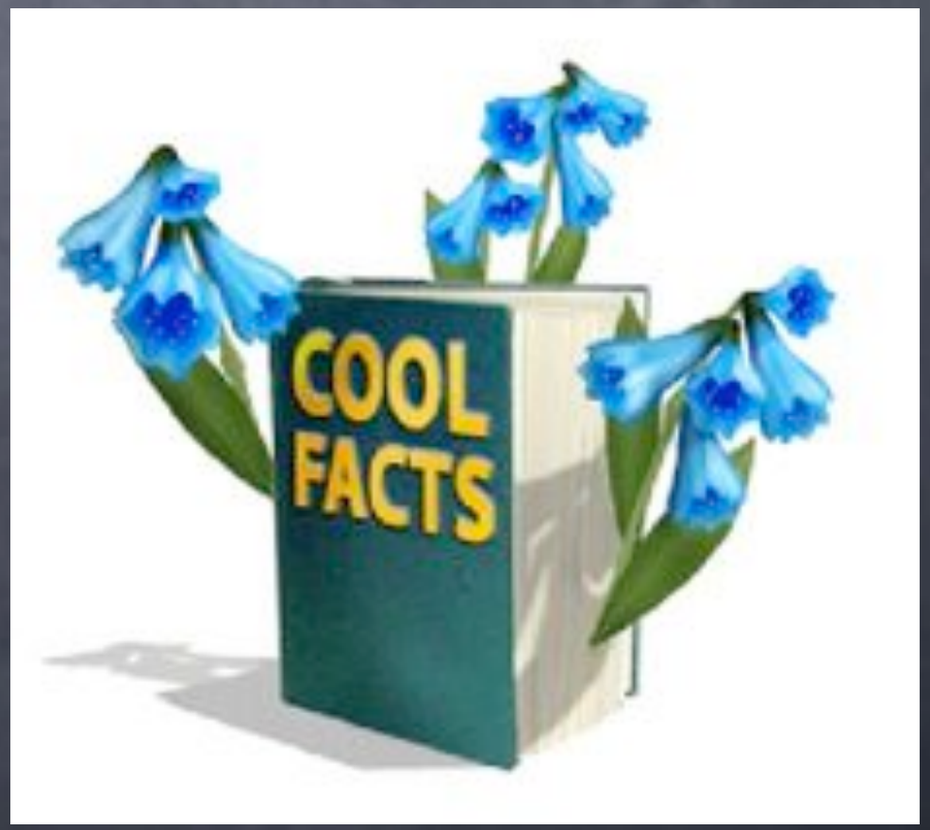
The mystery of fault tremor; where, when, how, and why?

mostly review



Empirical talk

- Tremor
  - Tectonic setting
  - Appearance
  - Sensitivity to weak stresses
  - Regularity and irregularity
  - Magnitude-frequency
  - Migration
  - more ...
- Bold Speculation will follow later



Locked, slipping, and bizarre

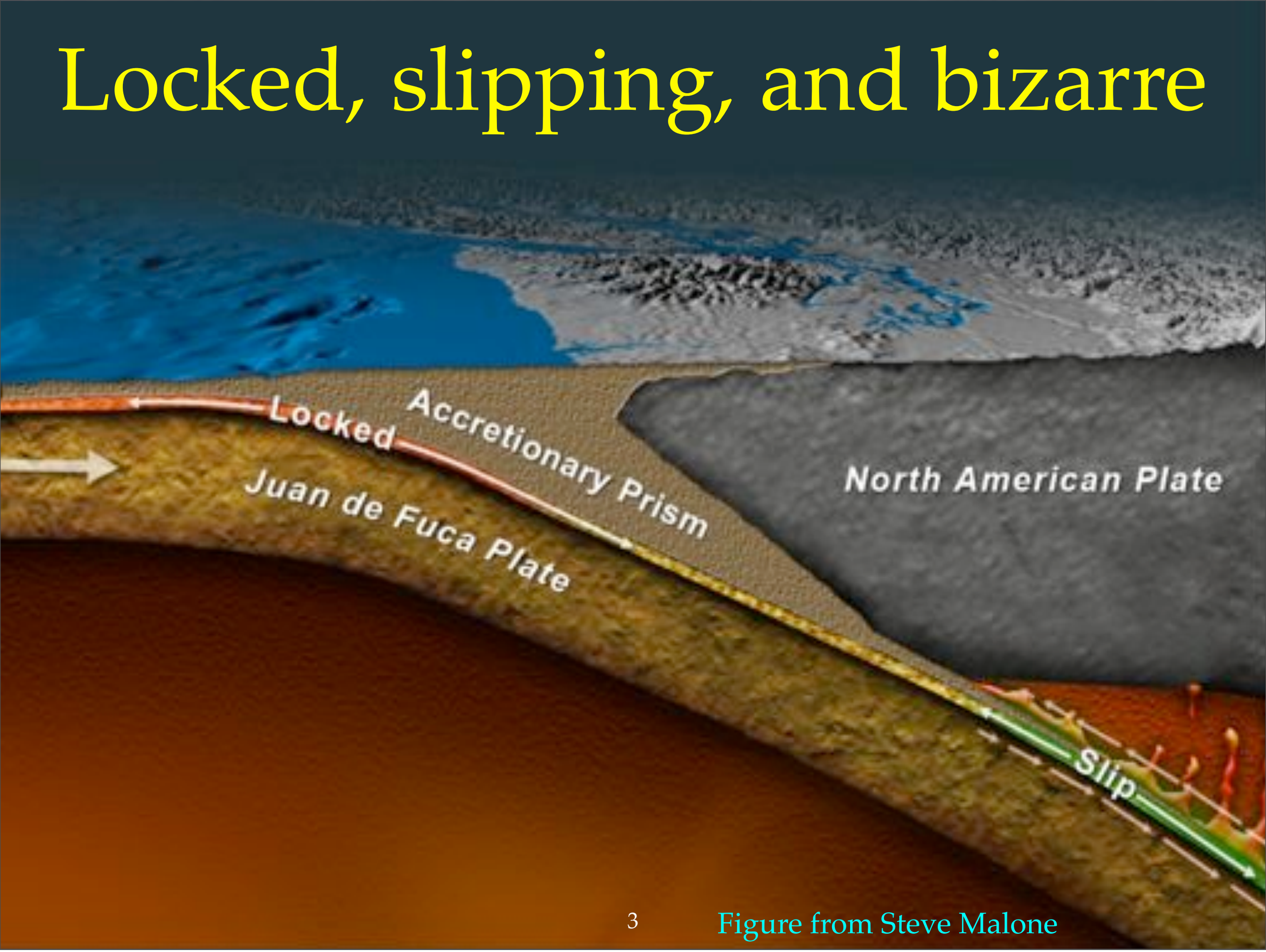


Figure from Steve Malone

Locked, slipping, and bizarre

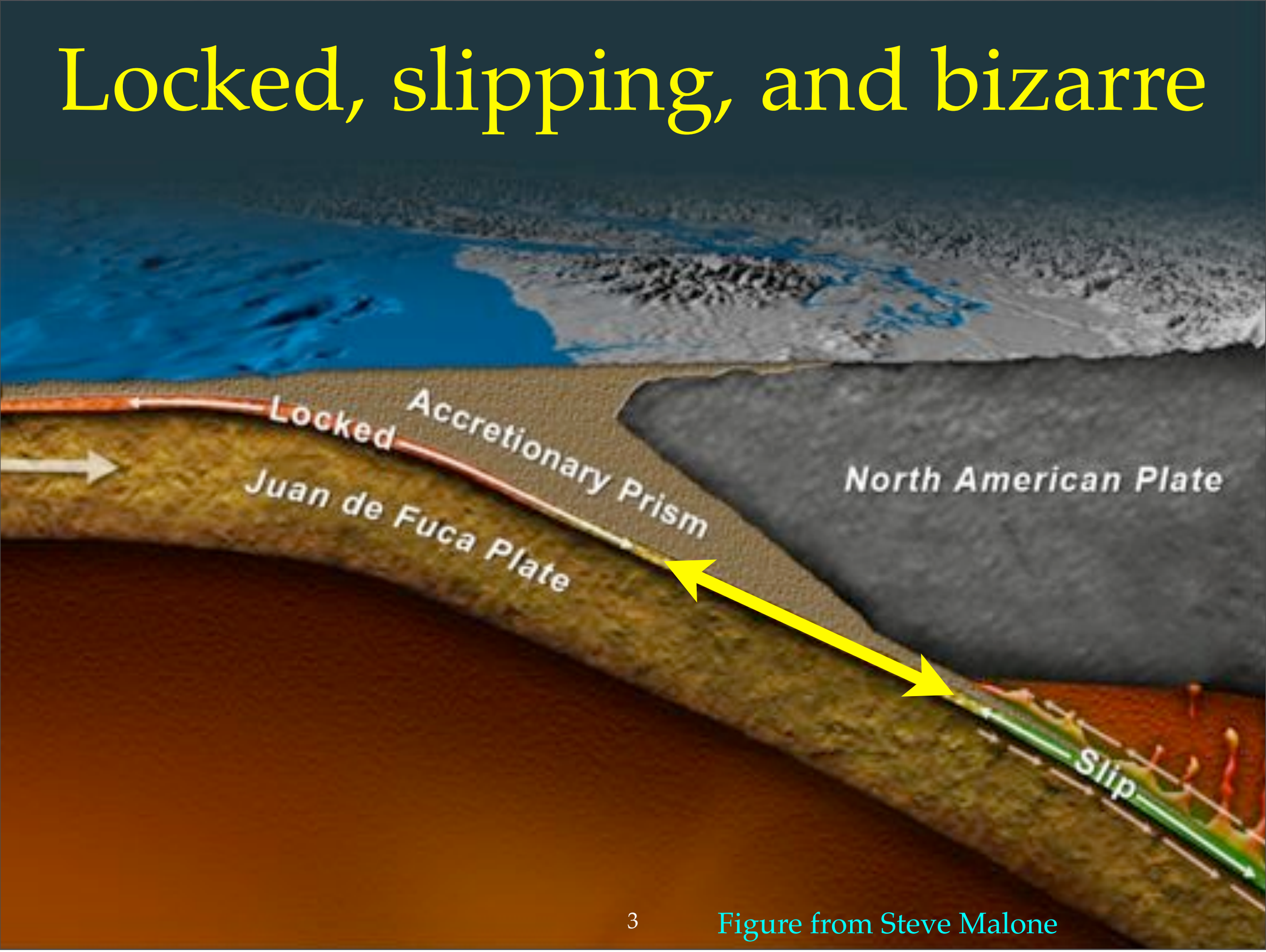
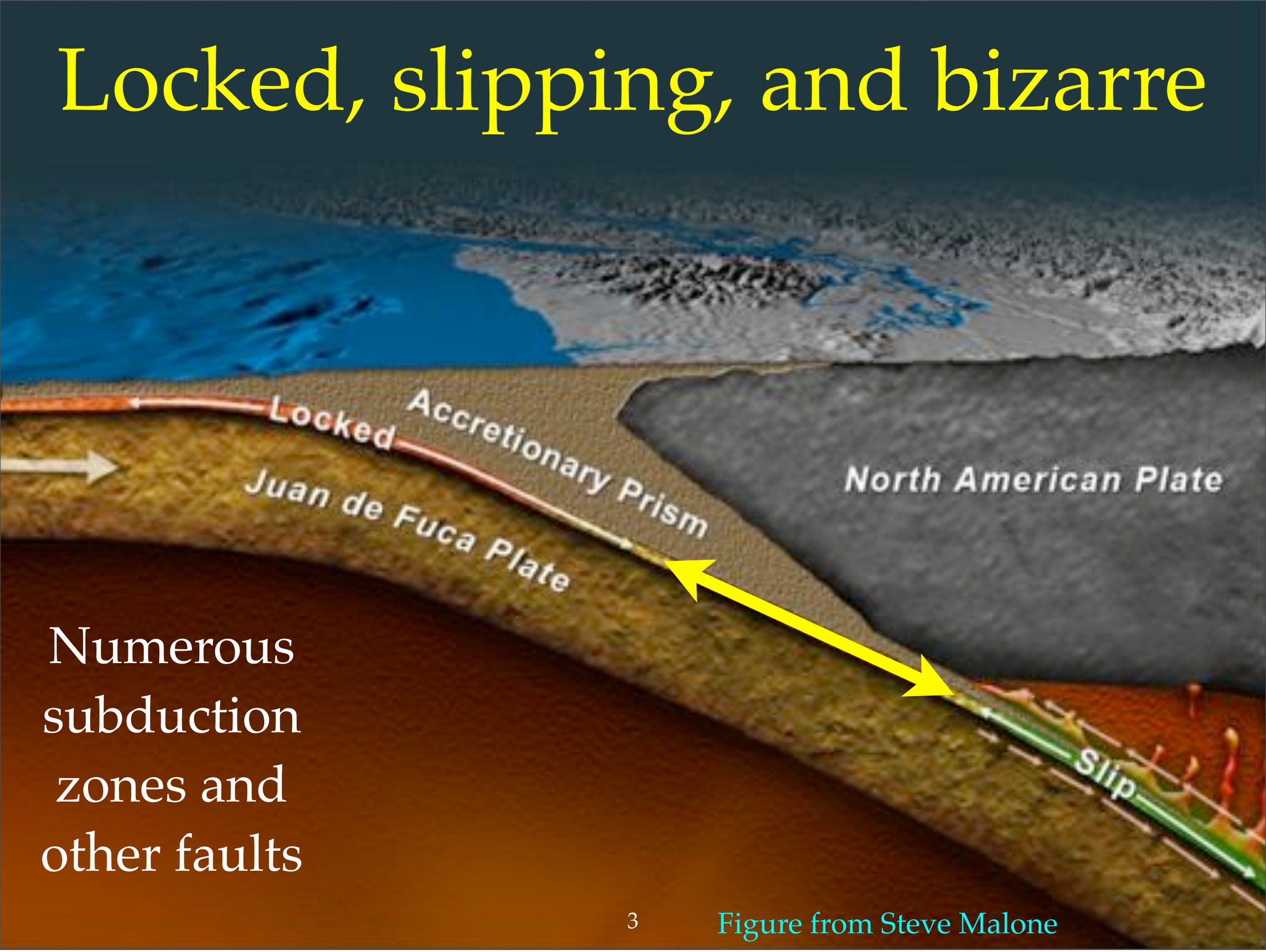


Figure from Steve Malone

Locked, slipping, and bizarre

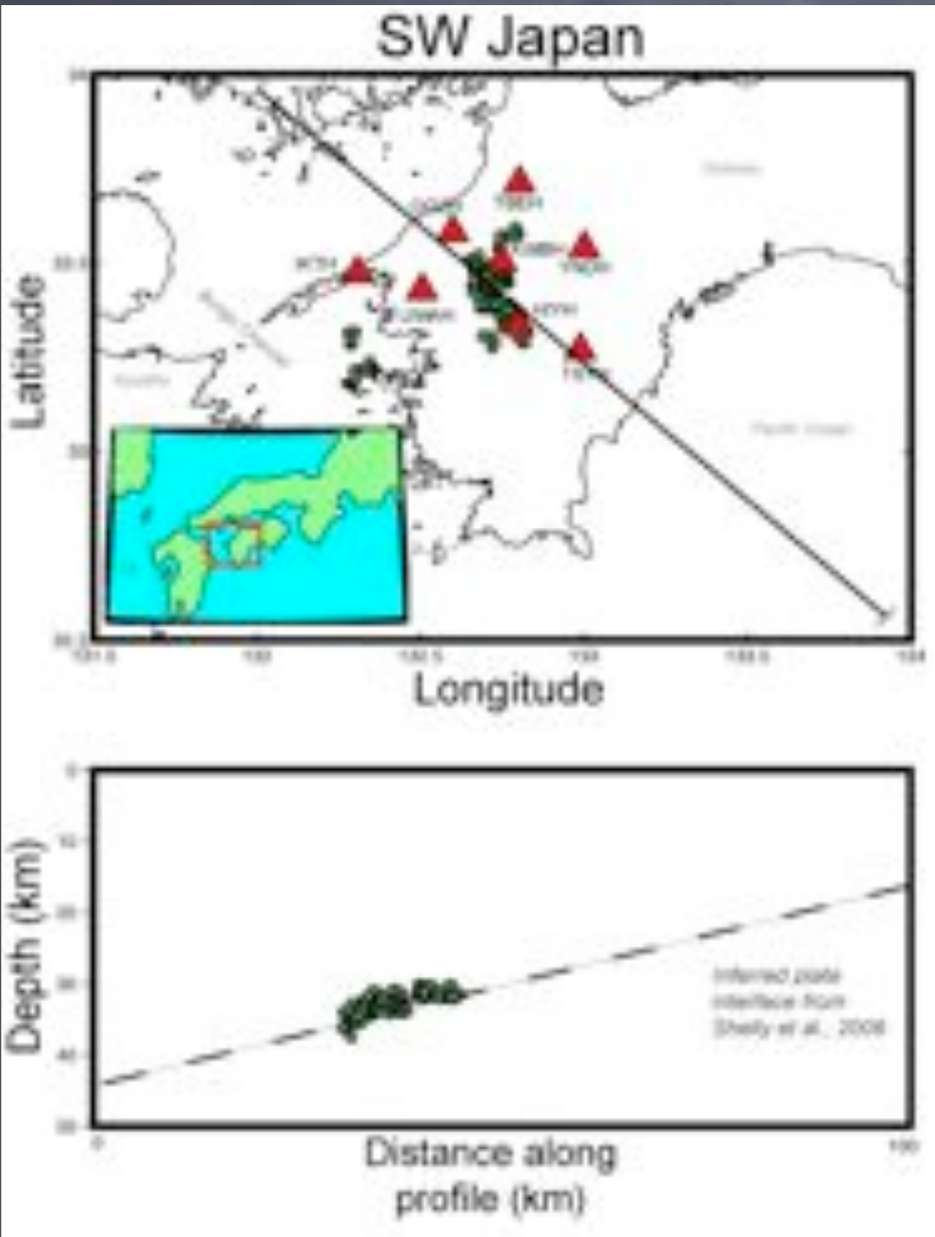


Numerous subduction zones and other faults

Figure from Steve Malone

Global studies generally find tremor occurring at the plate interface

Autocorrelation location of low-frequency quakes that comprise tremor



Brown *et al.*, 2008

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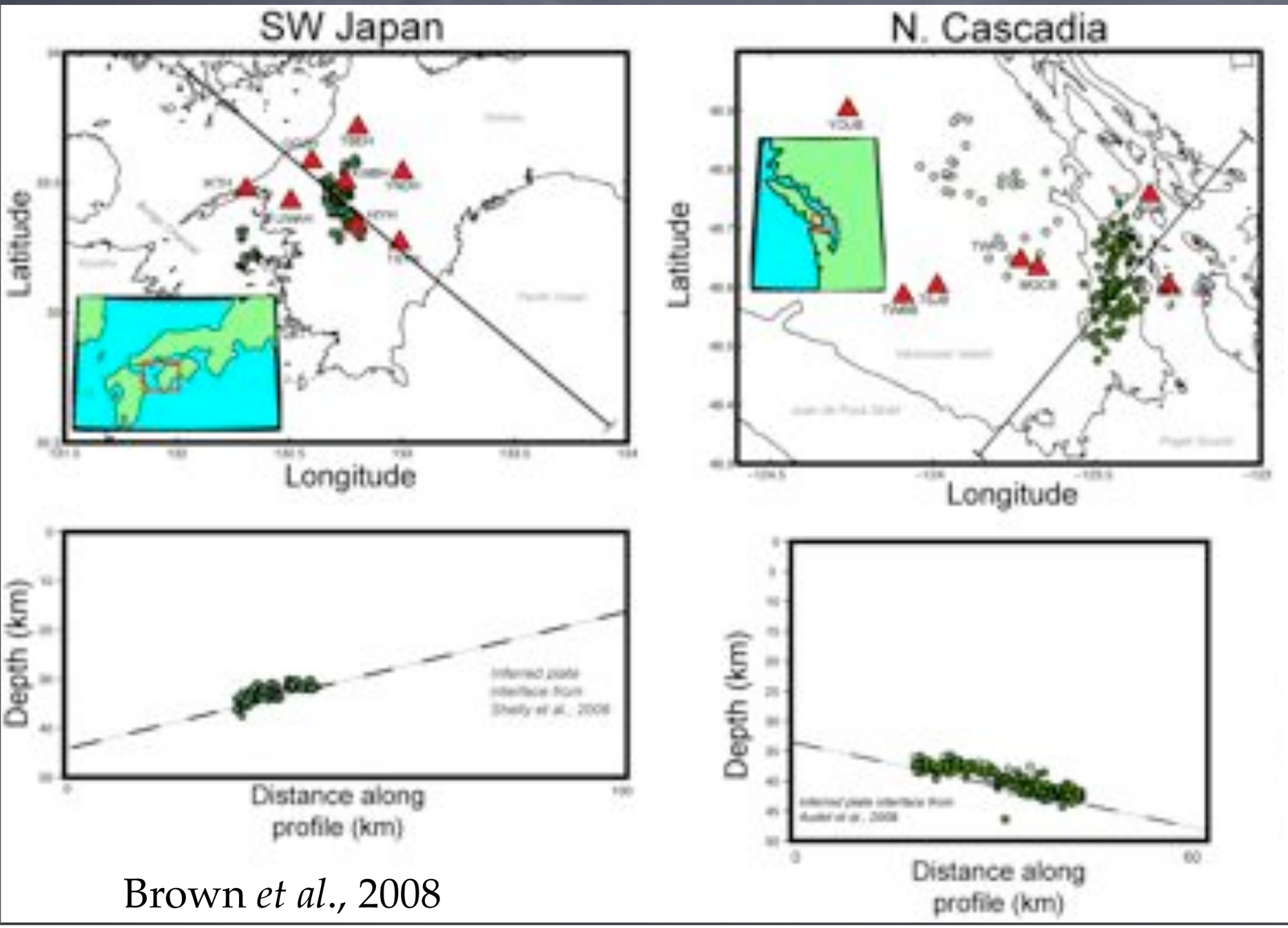

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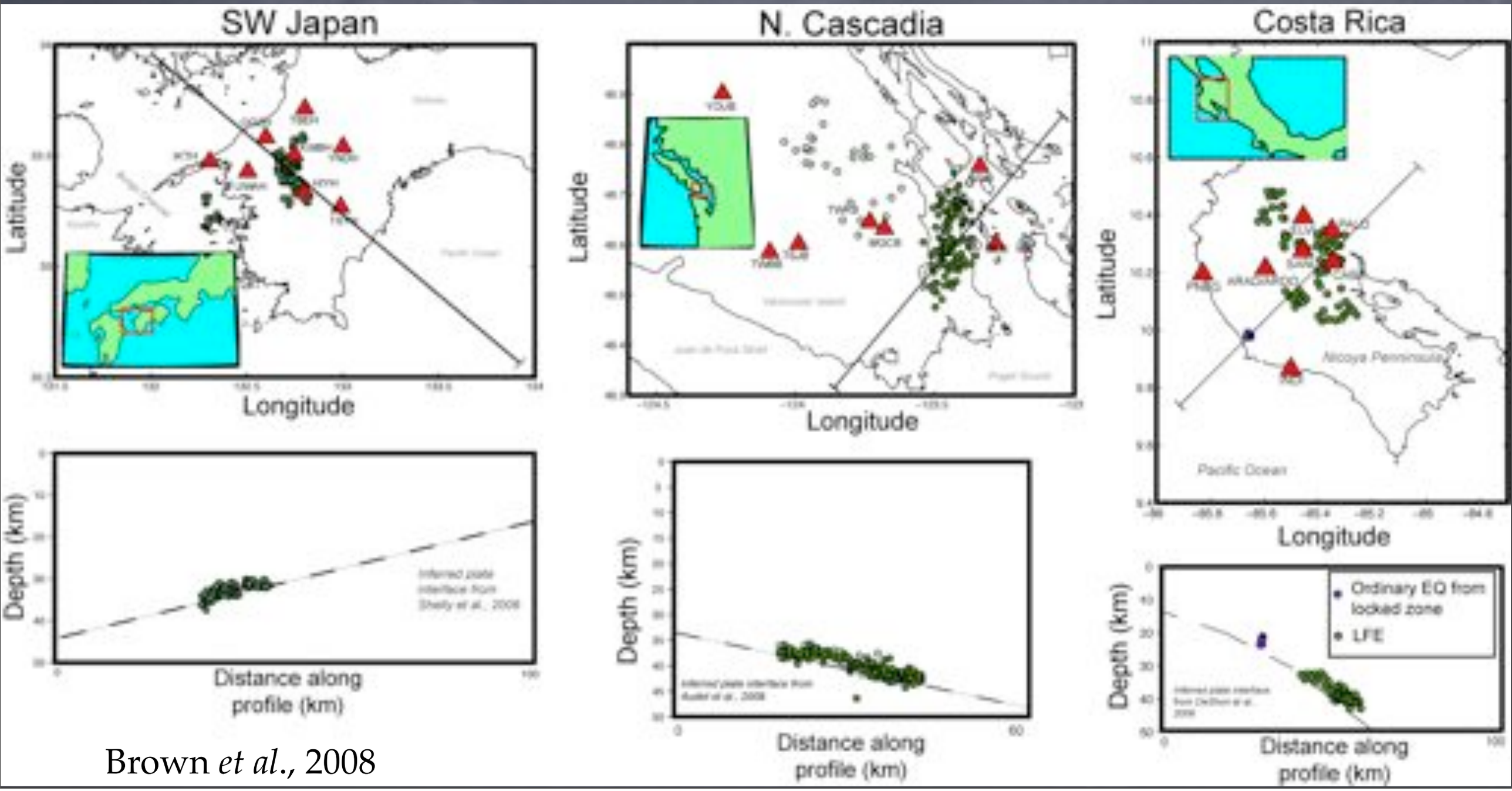
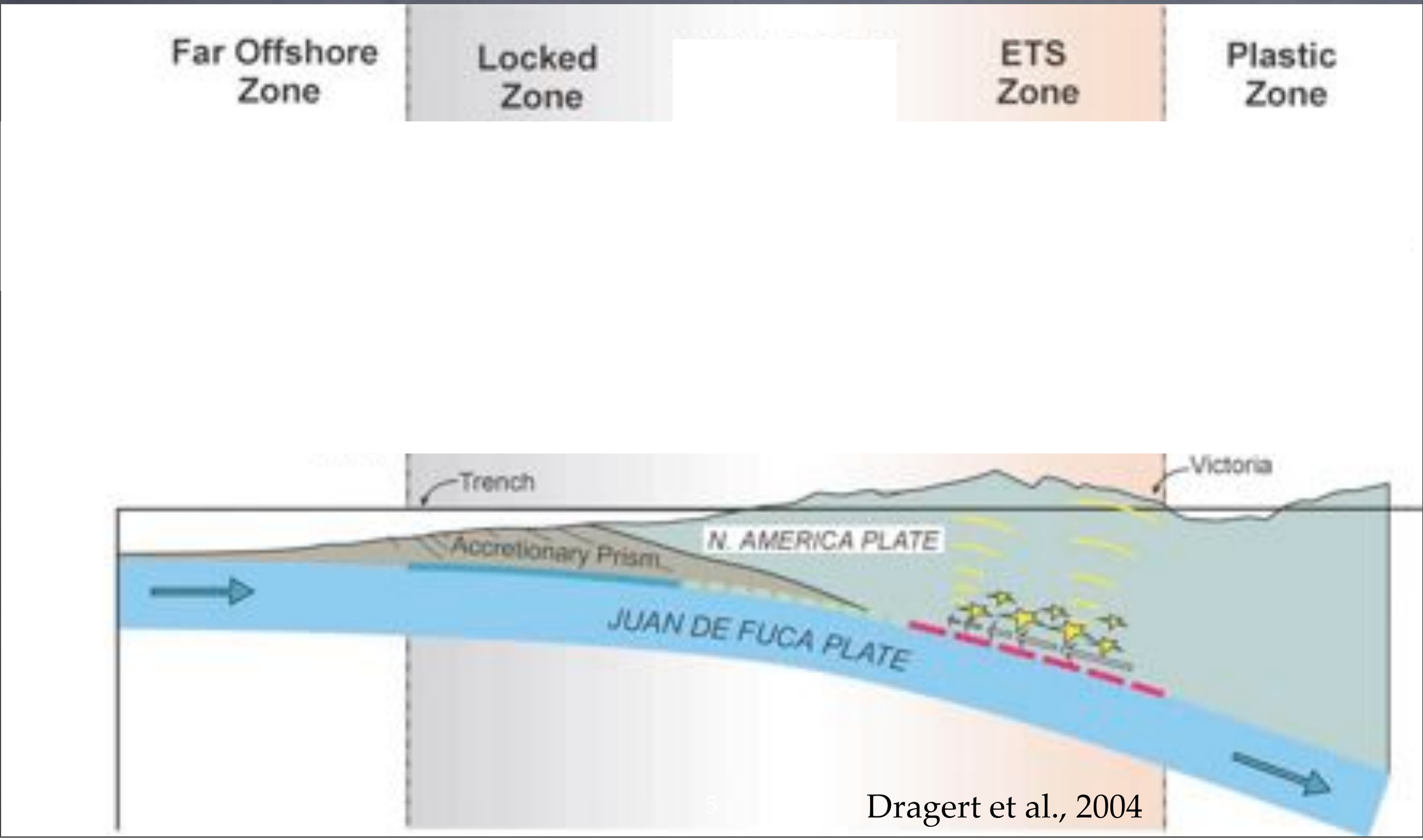


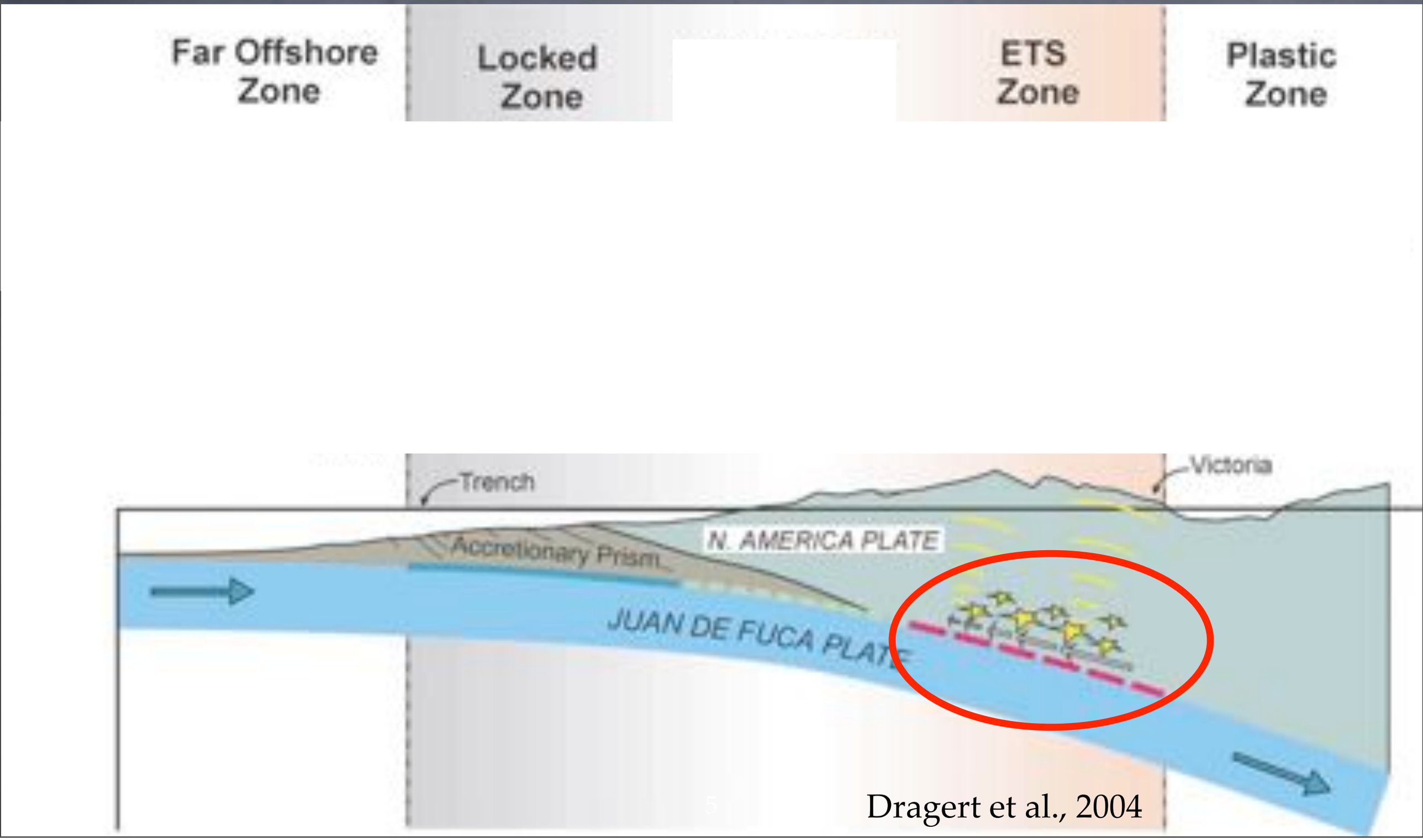
Brown *et al.*, 2008

Episodic Tremor and Slip schematic



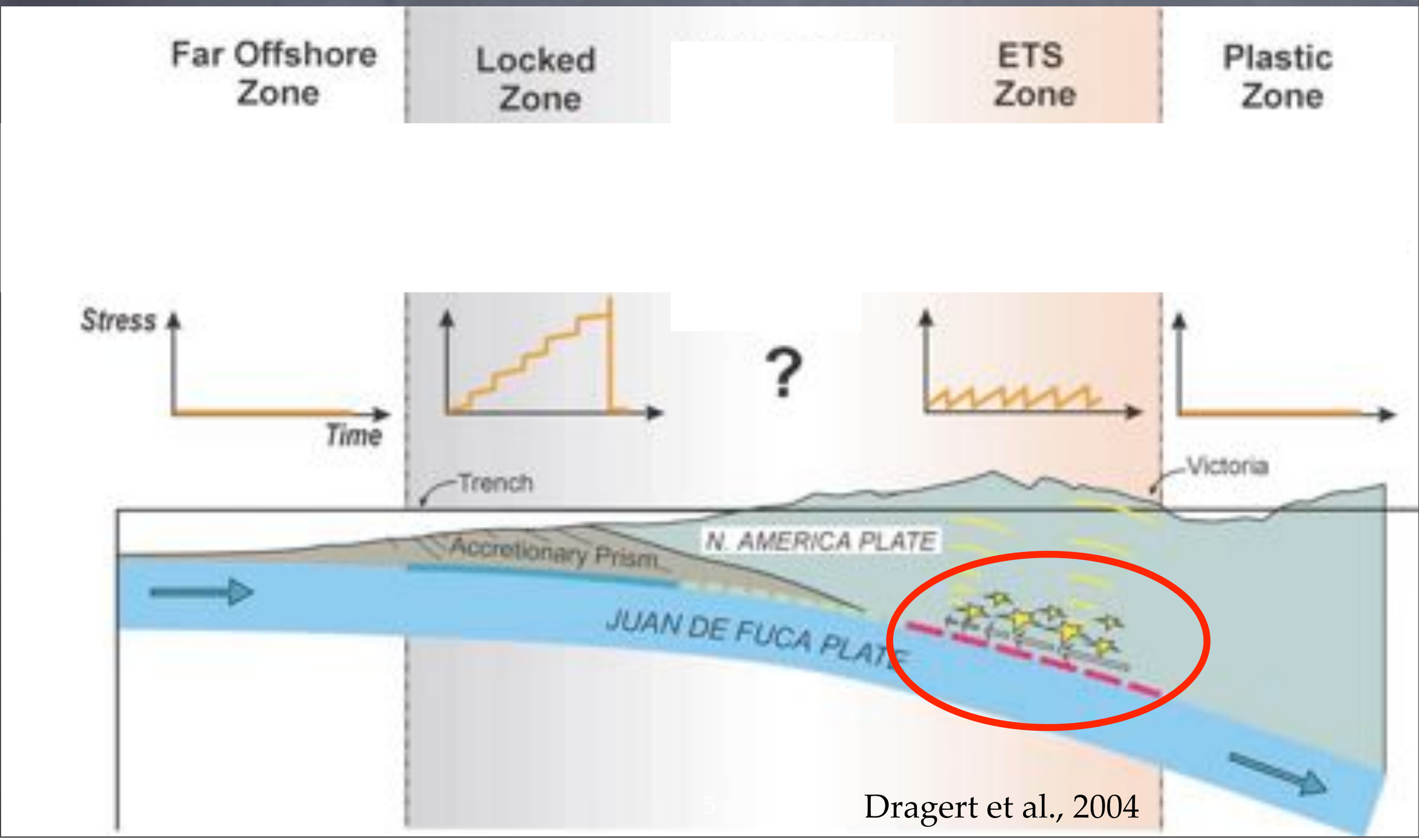
Dragert et al., 2004

Episodic Tremor and Slip schematic



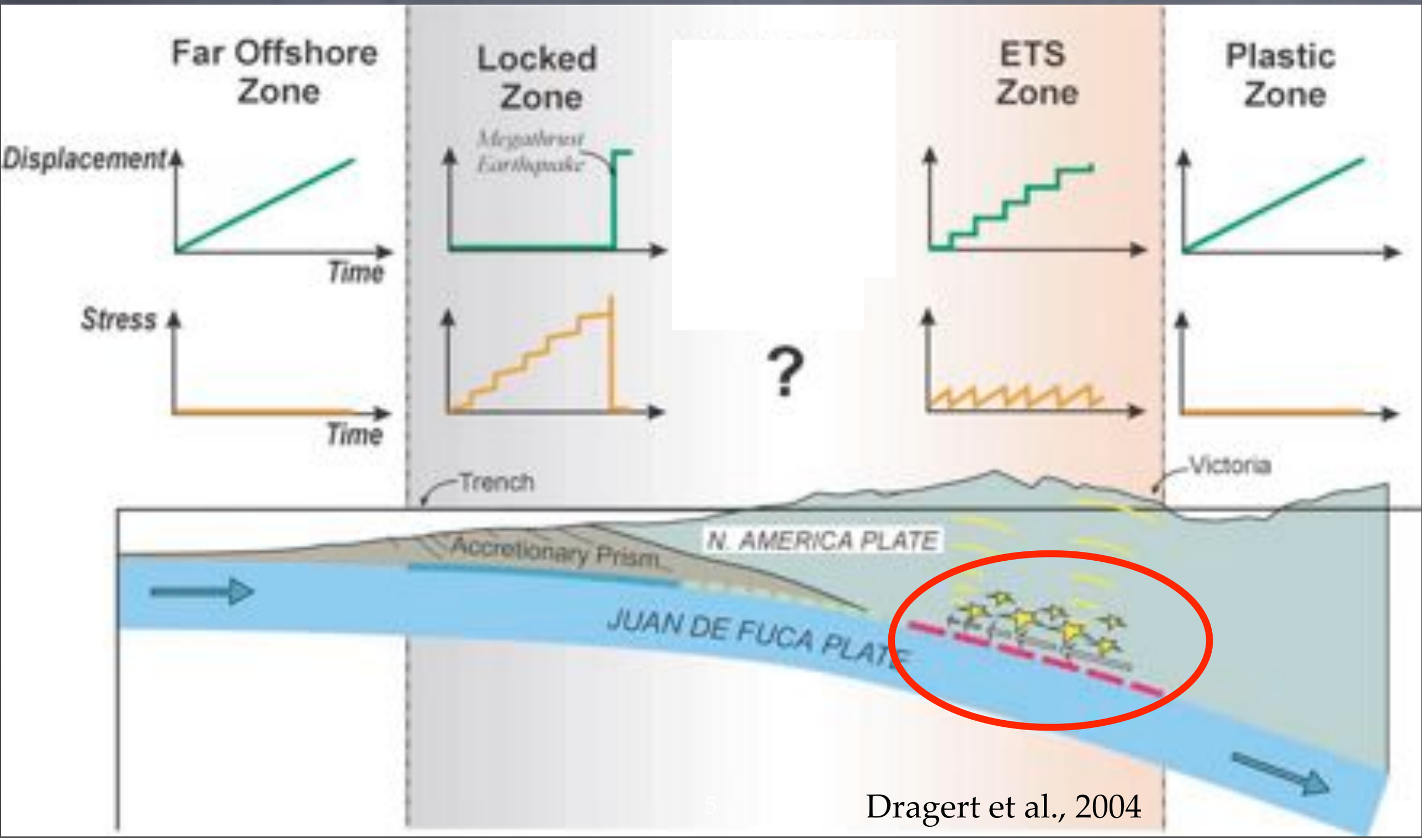
Dragert et al., 2004

Episodic Tremor and Slip schematic



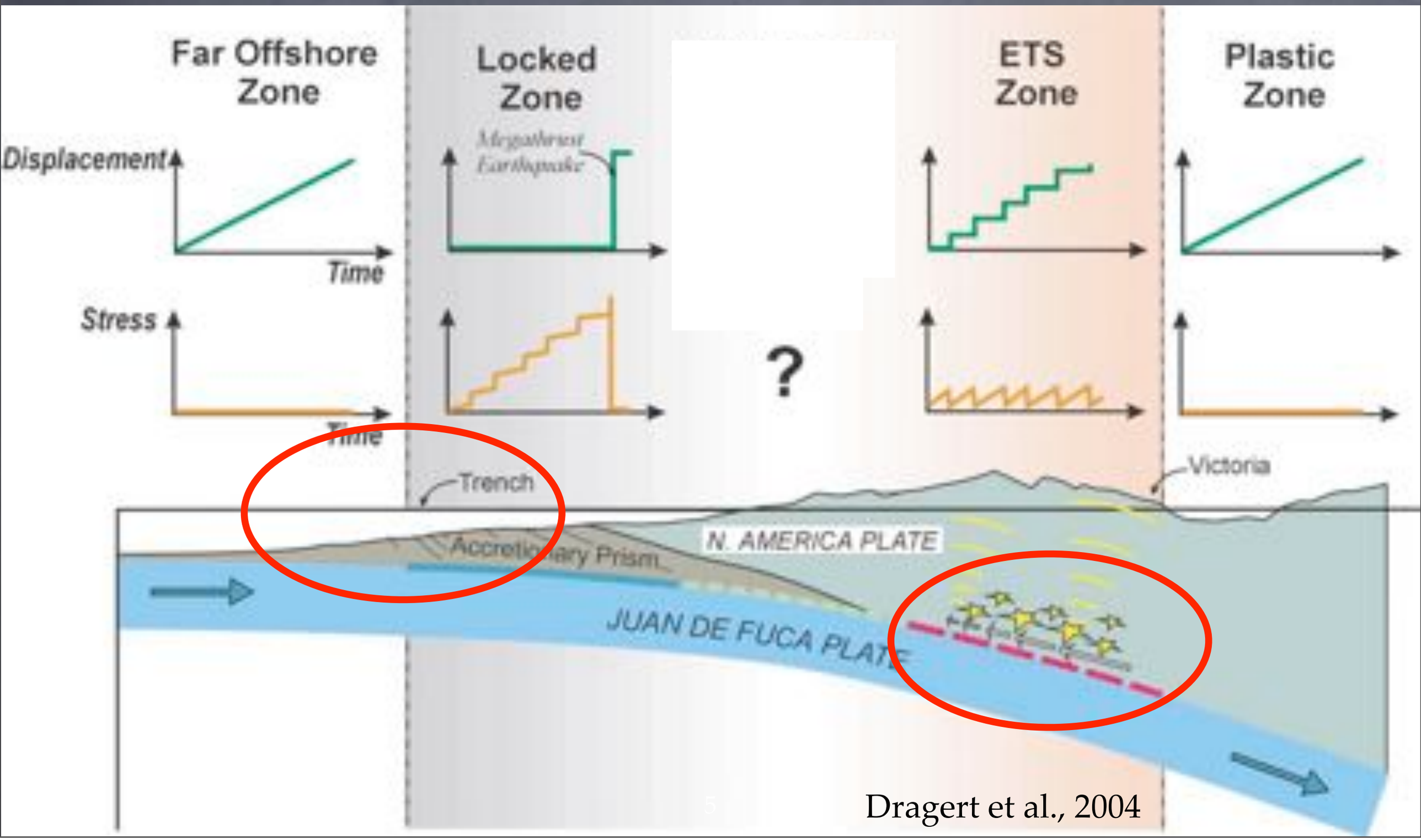
Dragert et al., 2004

Episodic Tremor and Slip schematic



Dragert et al., 2004

Episodic Tremor and Slip schematic



Dragert et al., 2004

central Japan cross-section

Locked

ETS region

Stable Slip

Depth [km]

30

60

Moho

Plate Interface

High Fluid Pressure

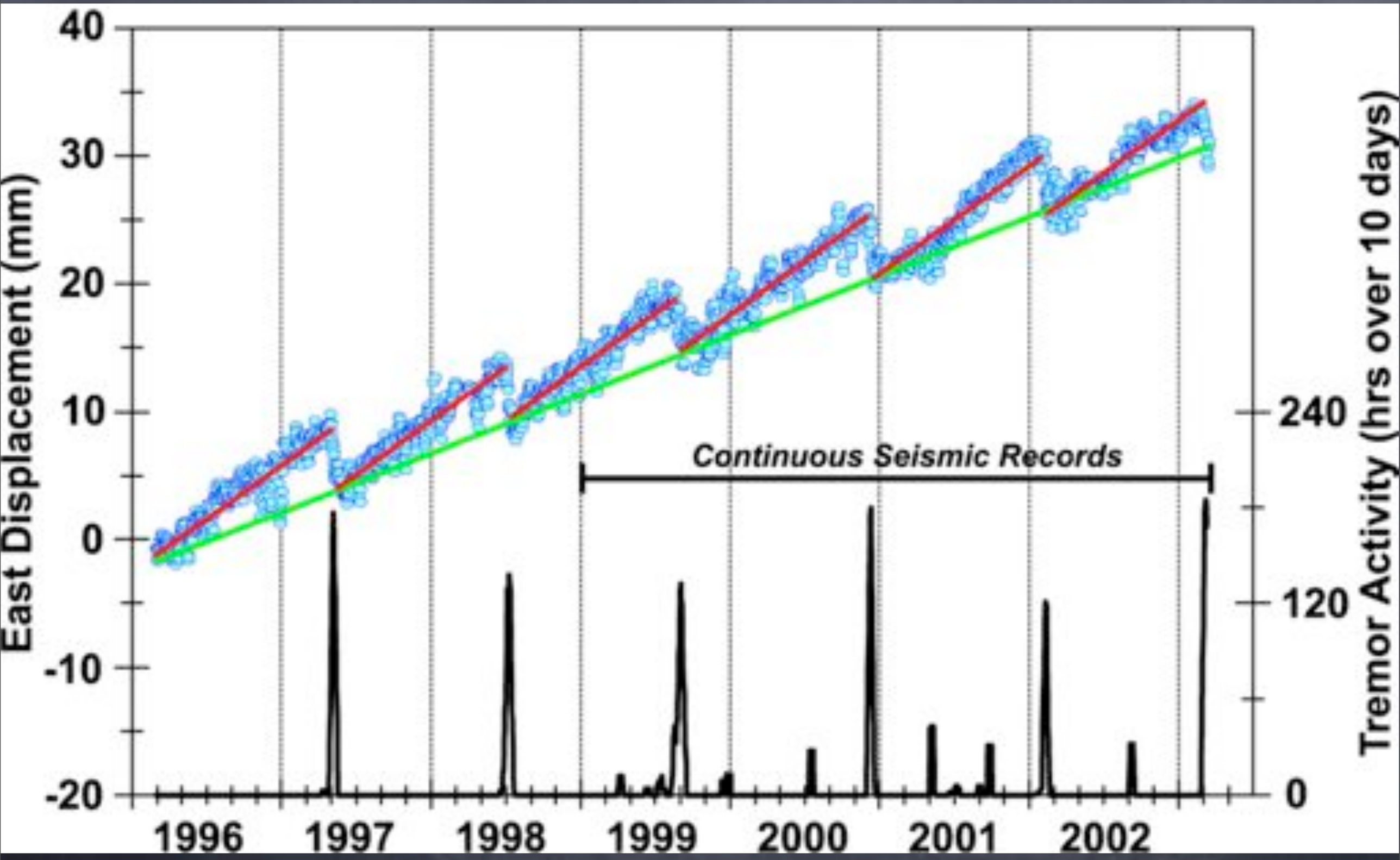
LFEs

subducting Moho

background is DVs (%)

Hirose et al., 2008, Shelly et al., 2006, Audet, 2009, Abers et al., 2009

Periodic (14.5 mo) Cascadia recurrence



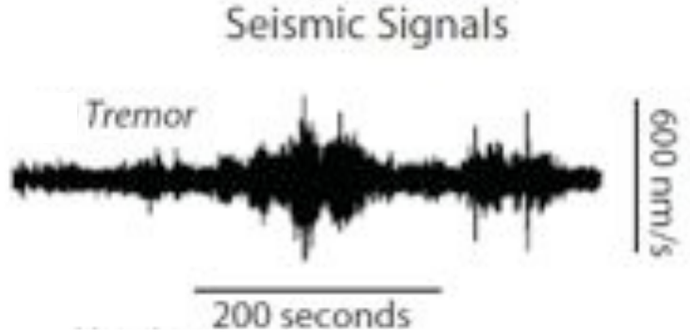
Rogers and Dragert, 2003

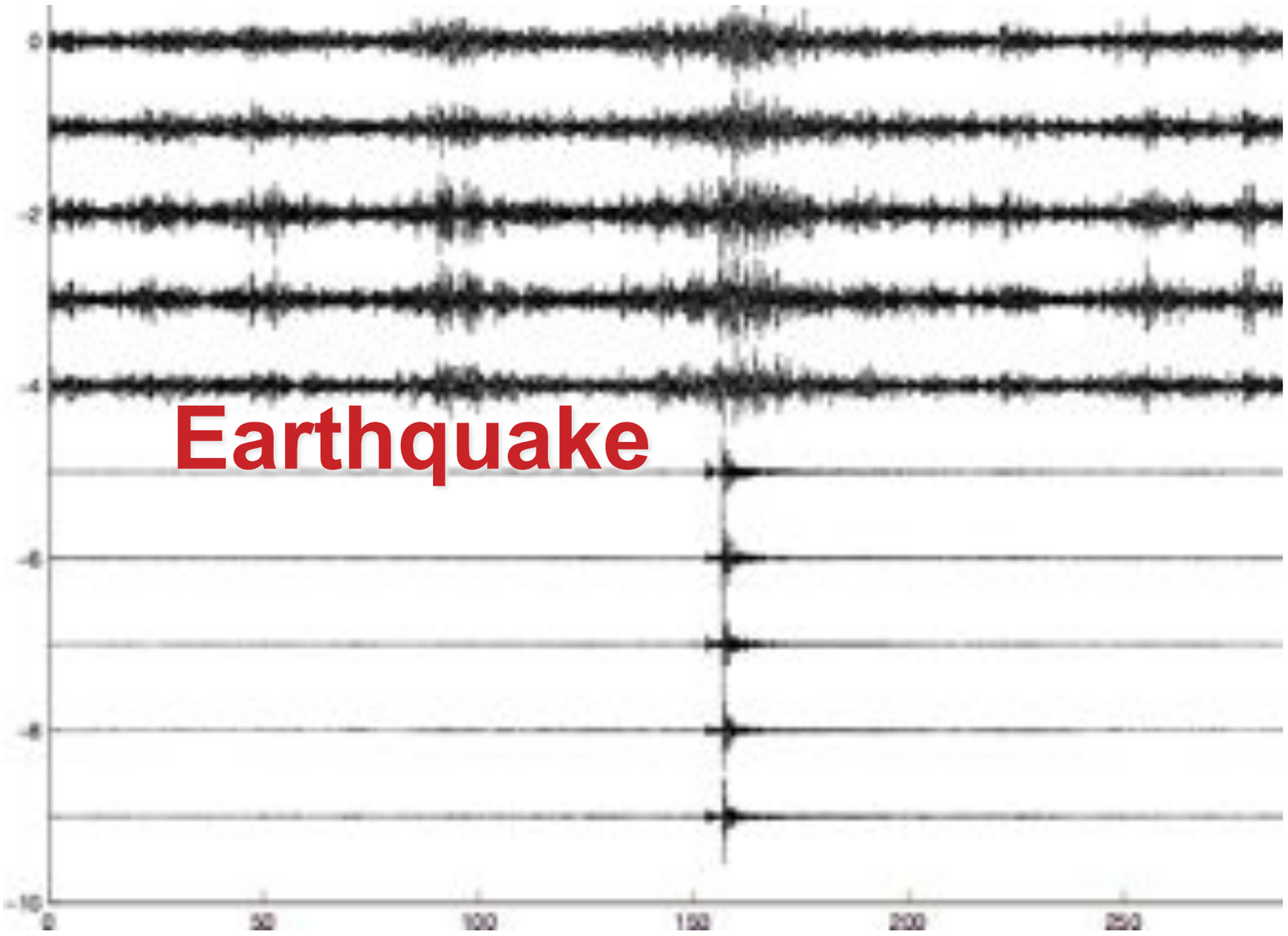
Multiple segments with regular recurrence intervals

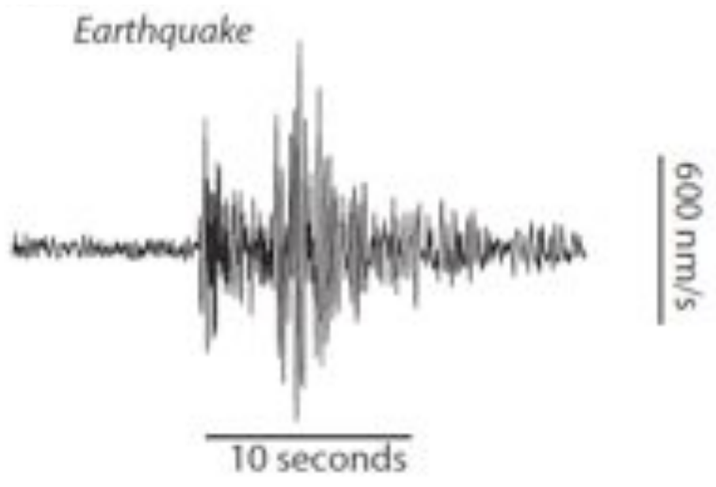
Color is ETS recurrence interval

Brudzinski & Allen, 2007

Tremor *vs* earthquake

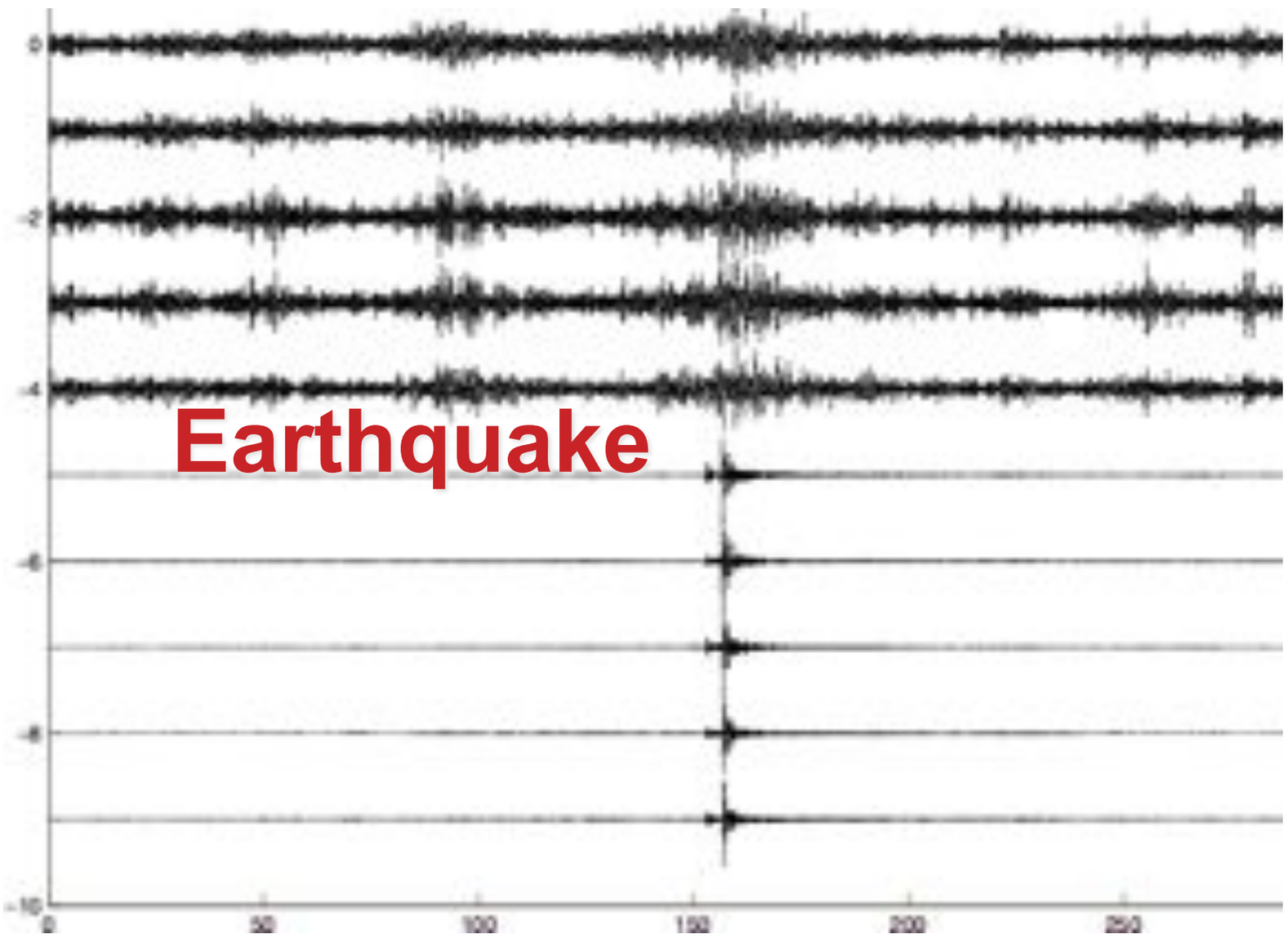


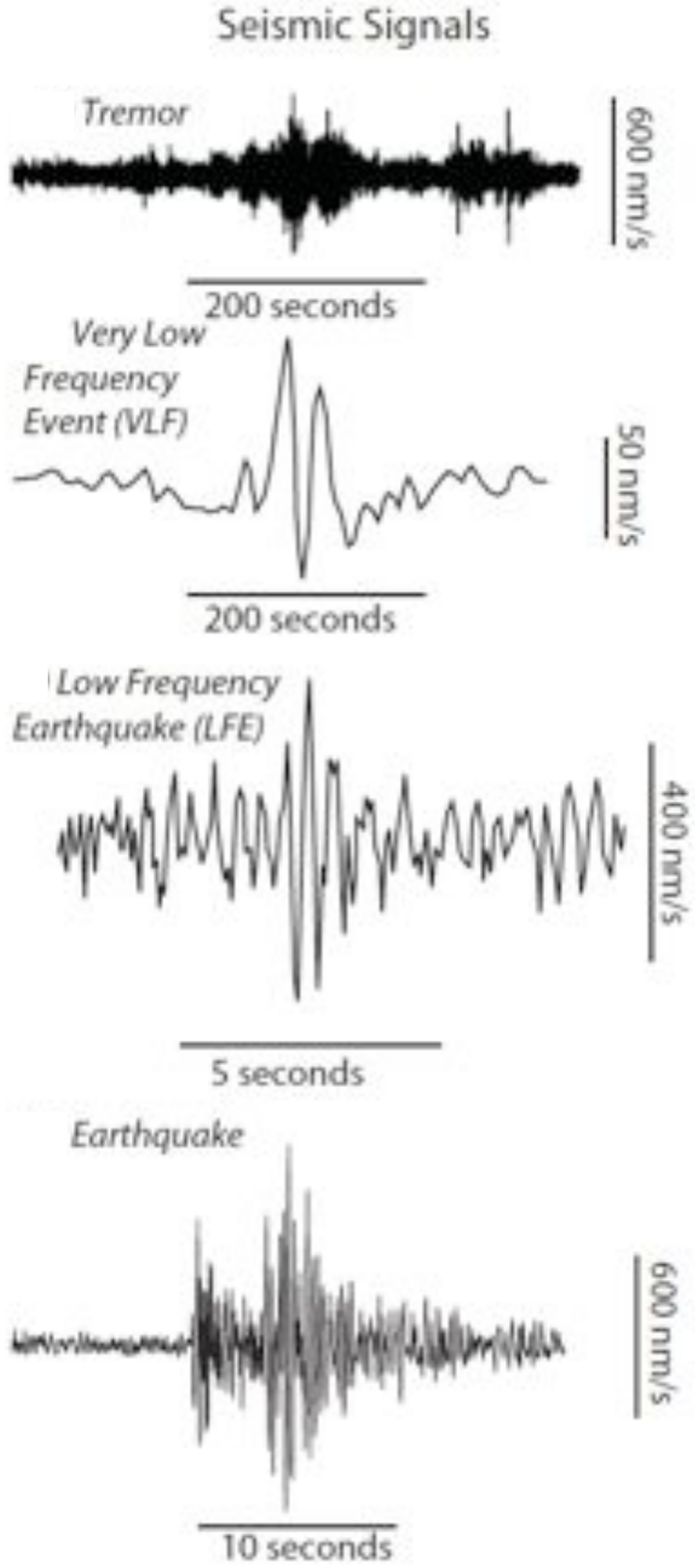




Gomberg *et al.*, GSA Bull., 2009

Tremor *vs* LFE *vs* earthquake





Gomberg *et al.*, GSA Bull., 2009

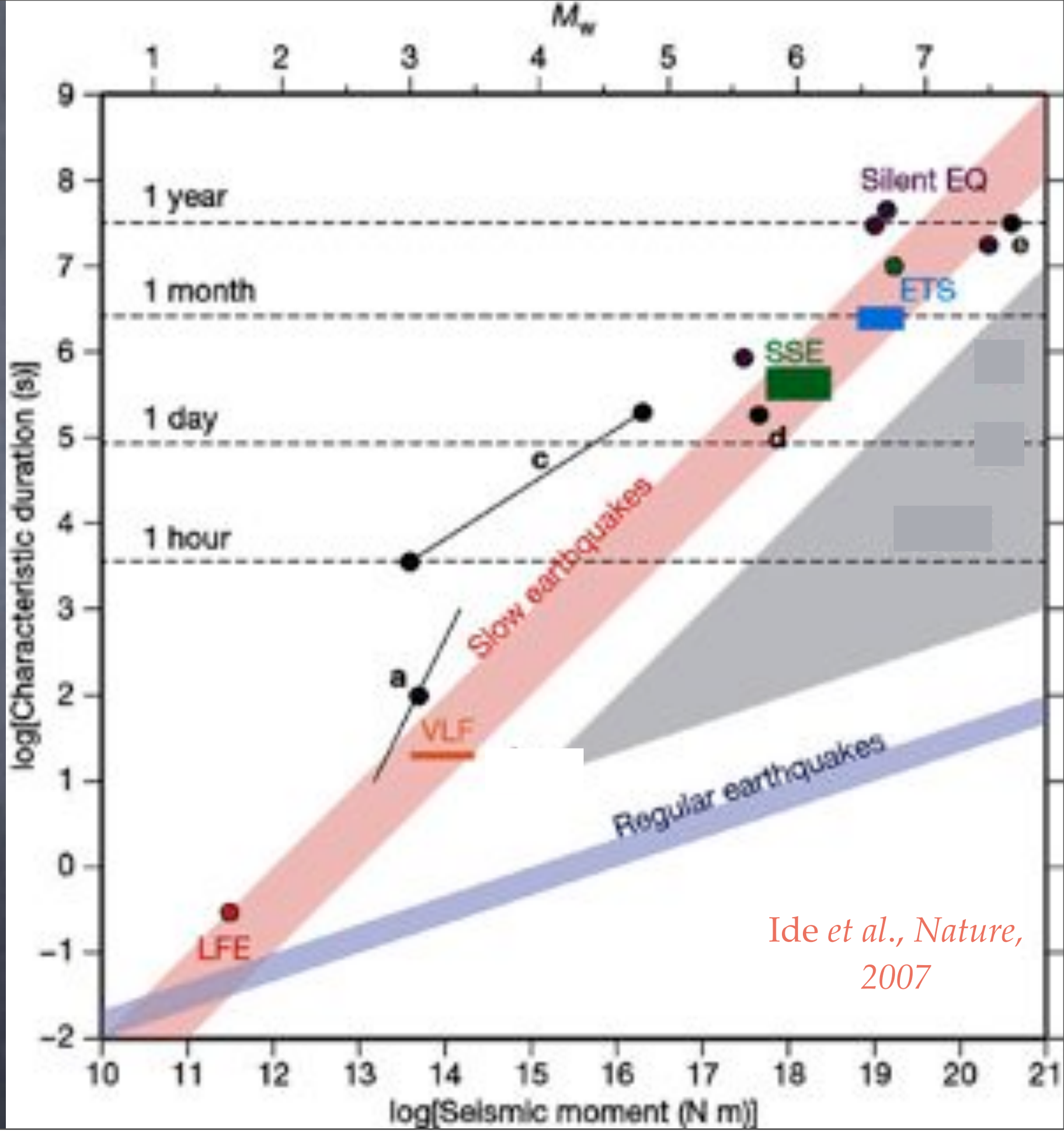
Two kinds of quakes

old

M ~ duration cubed

new

M ~ duration



Ide *et al., Nature, 2007*

Two kinds of quakes

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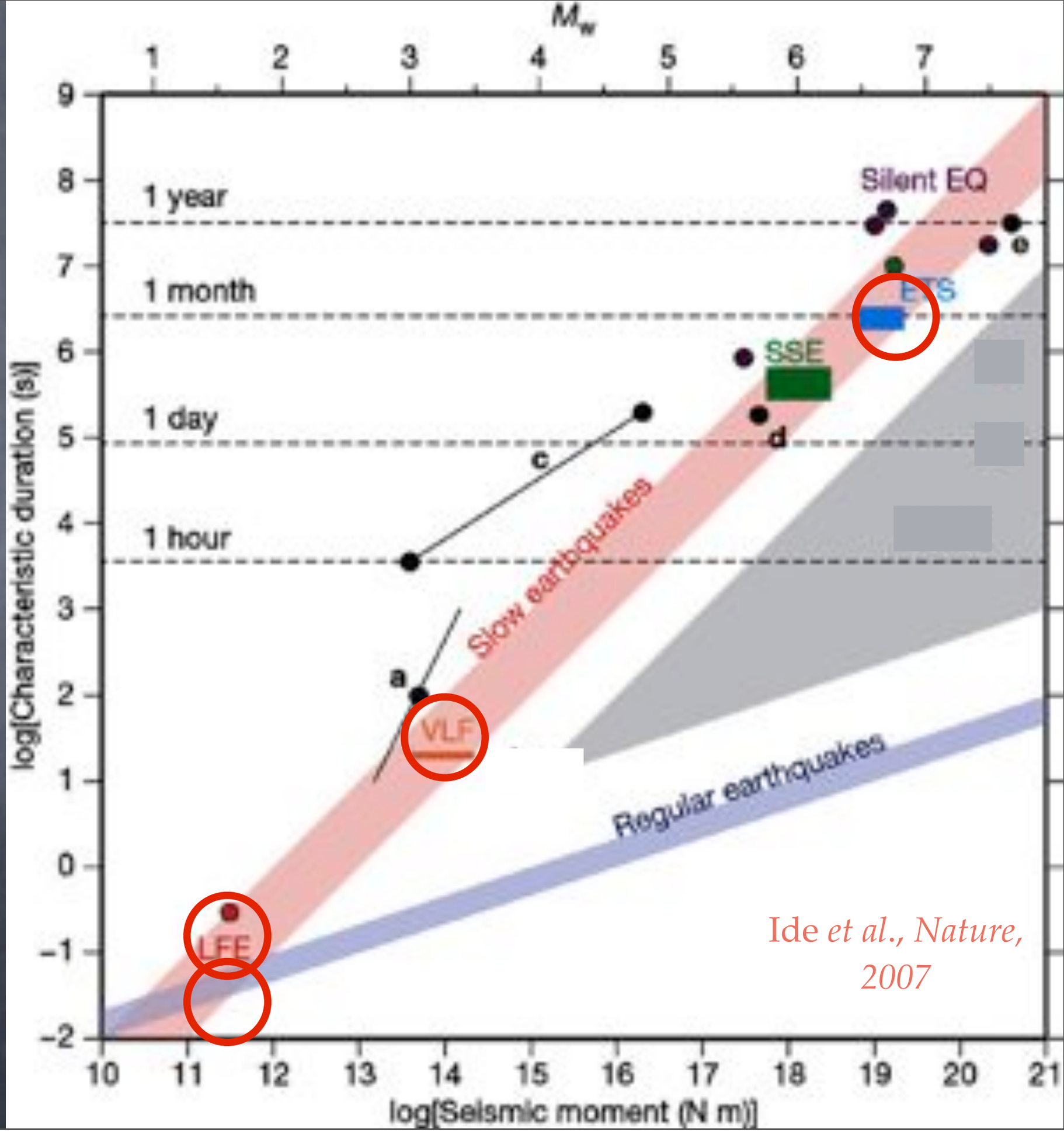
new

M ~ duration



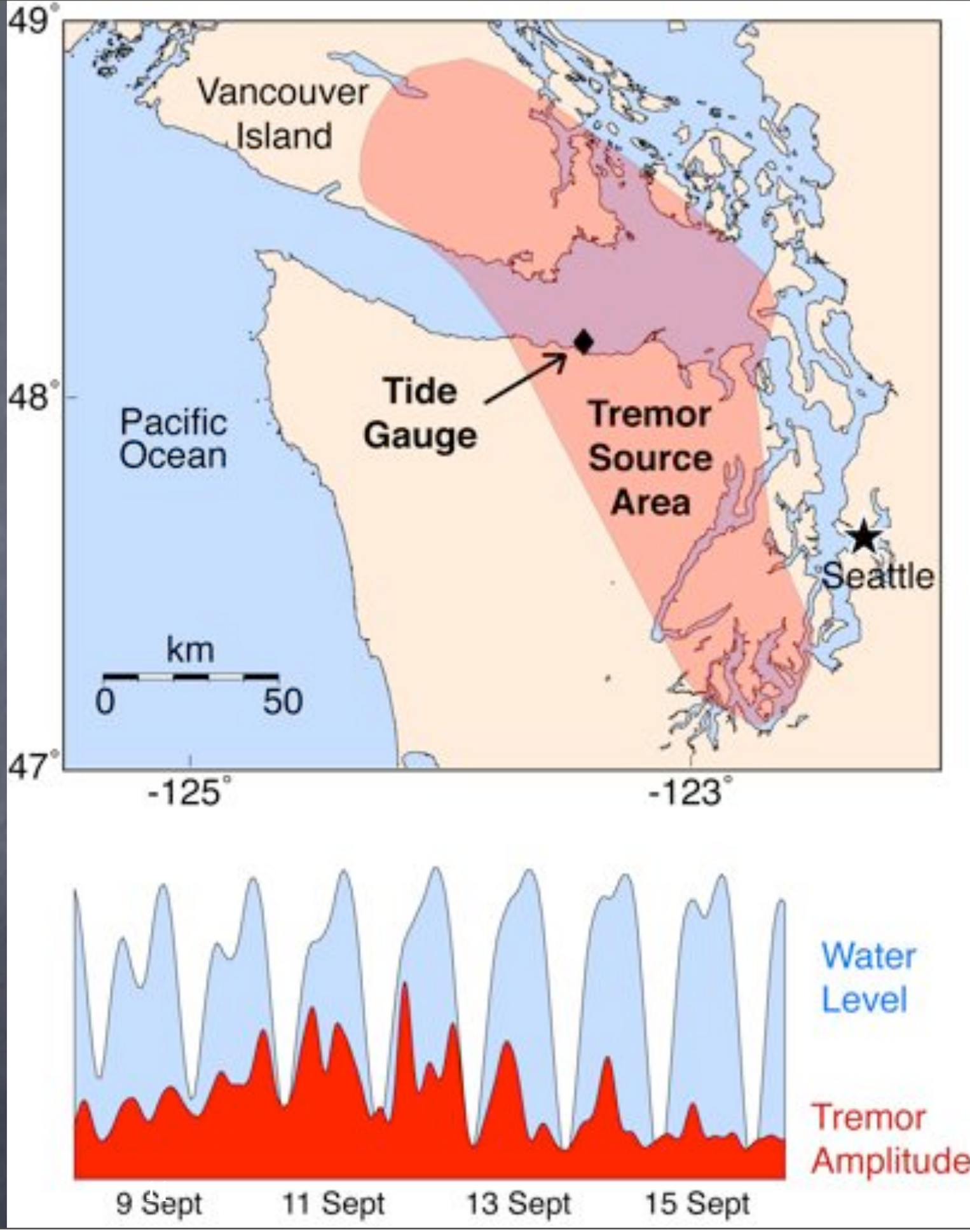
Ide *et al., Nature, 2007*

High water -> More tremor

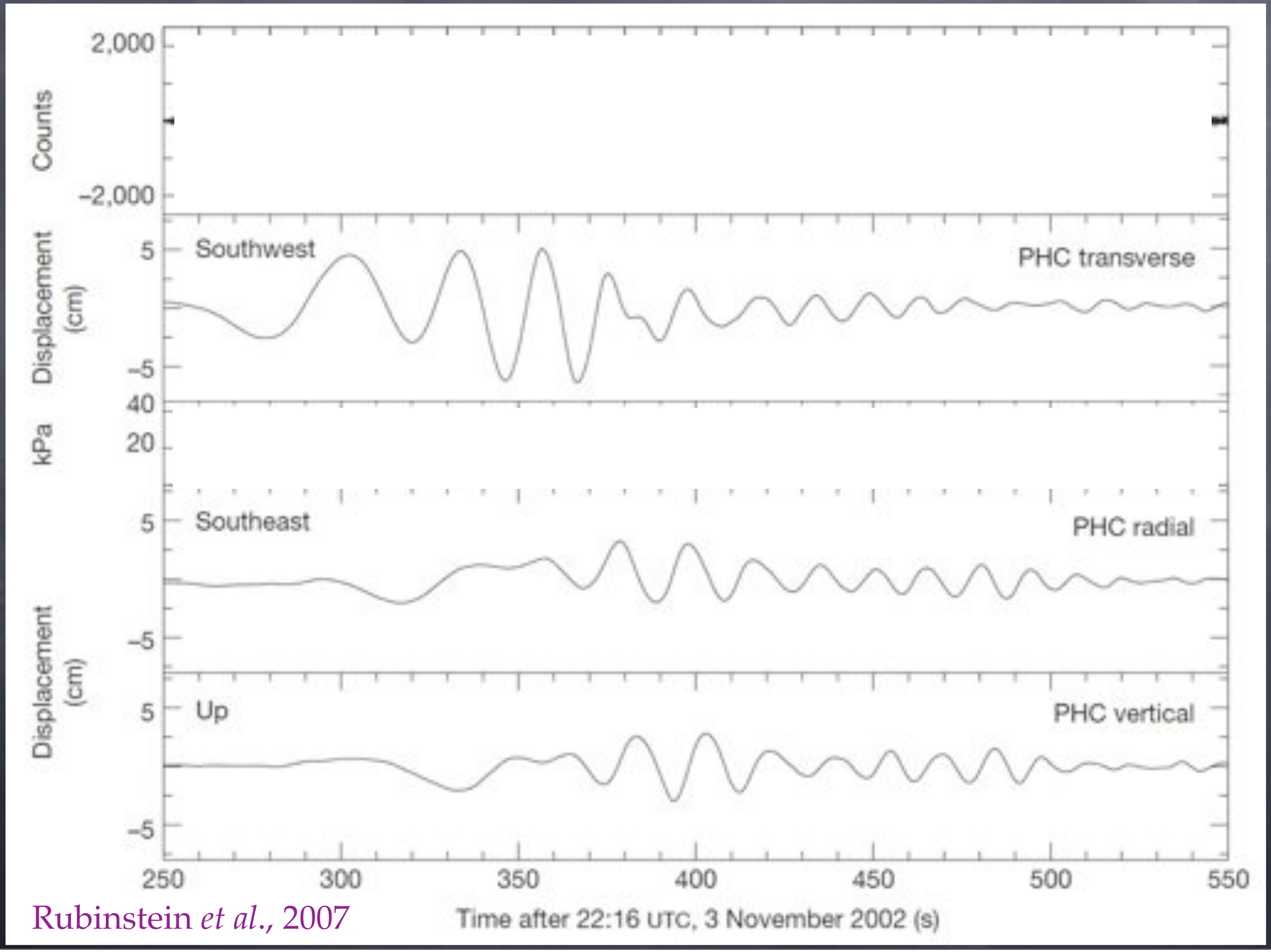
more stress -> more tremor

also seen for Japan, Vancouver Is

Rubinstein *et al.*, 2007



Tremor is modulated by surface wave stresses



Rubinstein *et al.*, 2007

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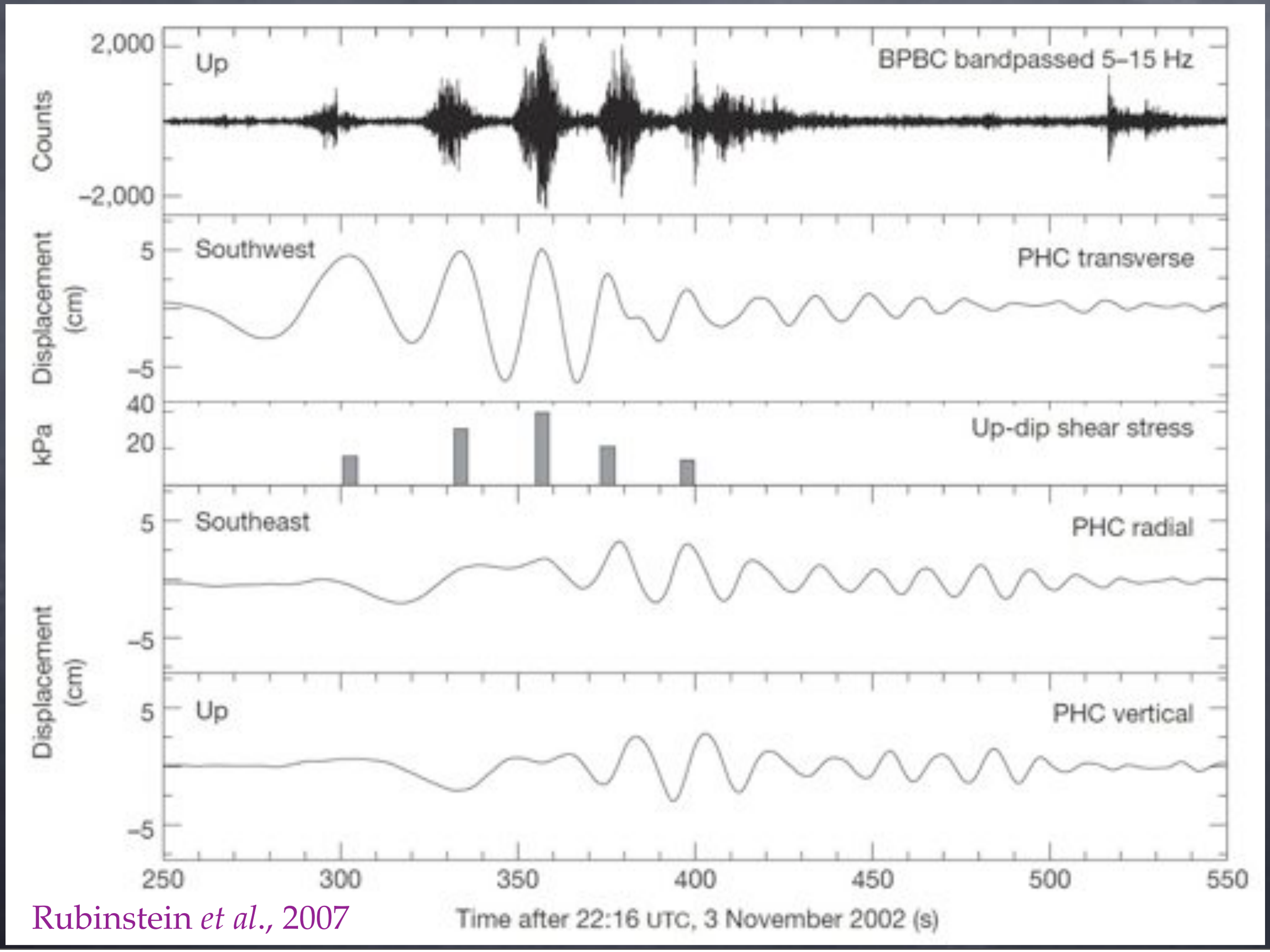
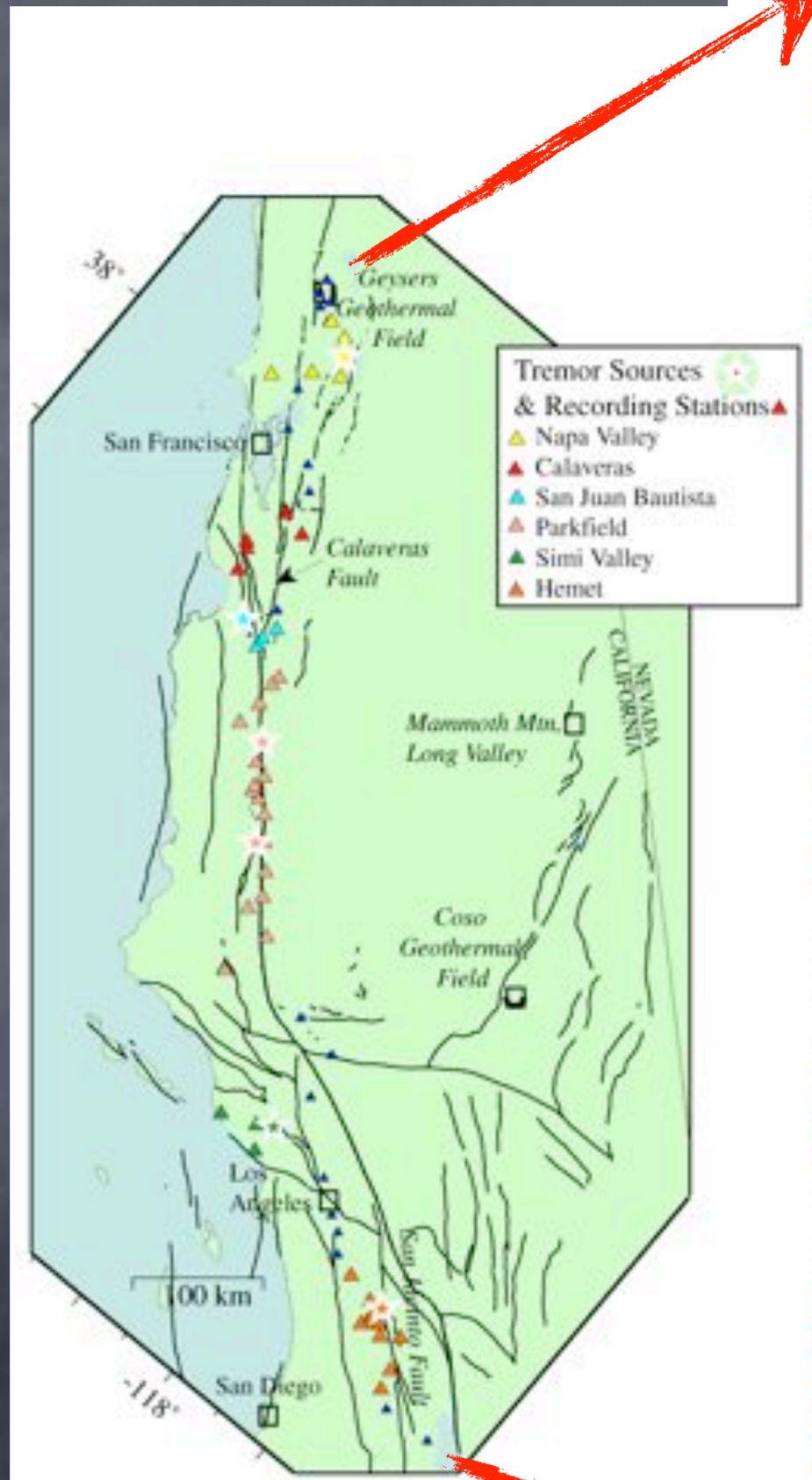


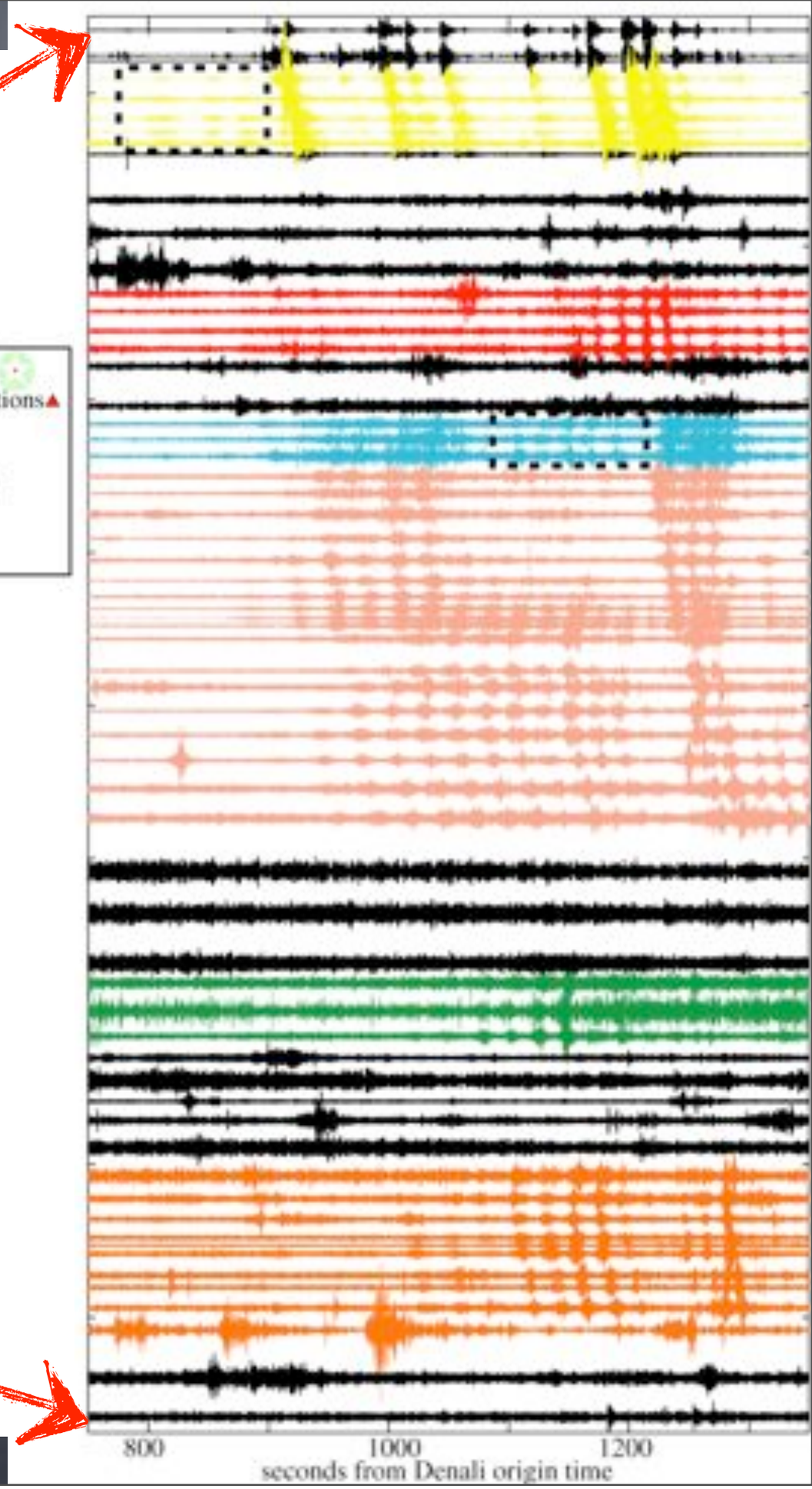
Rubinstein *et al.*, 2007

Widespread tremor from 2002 Denali

7 spots along SAF

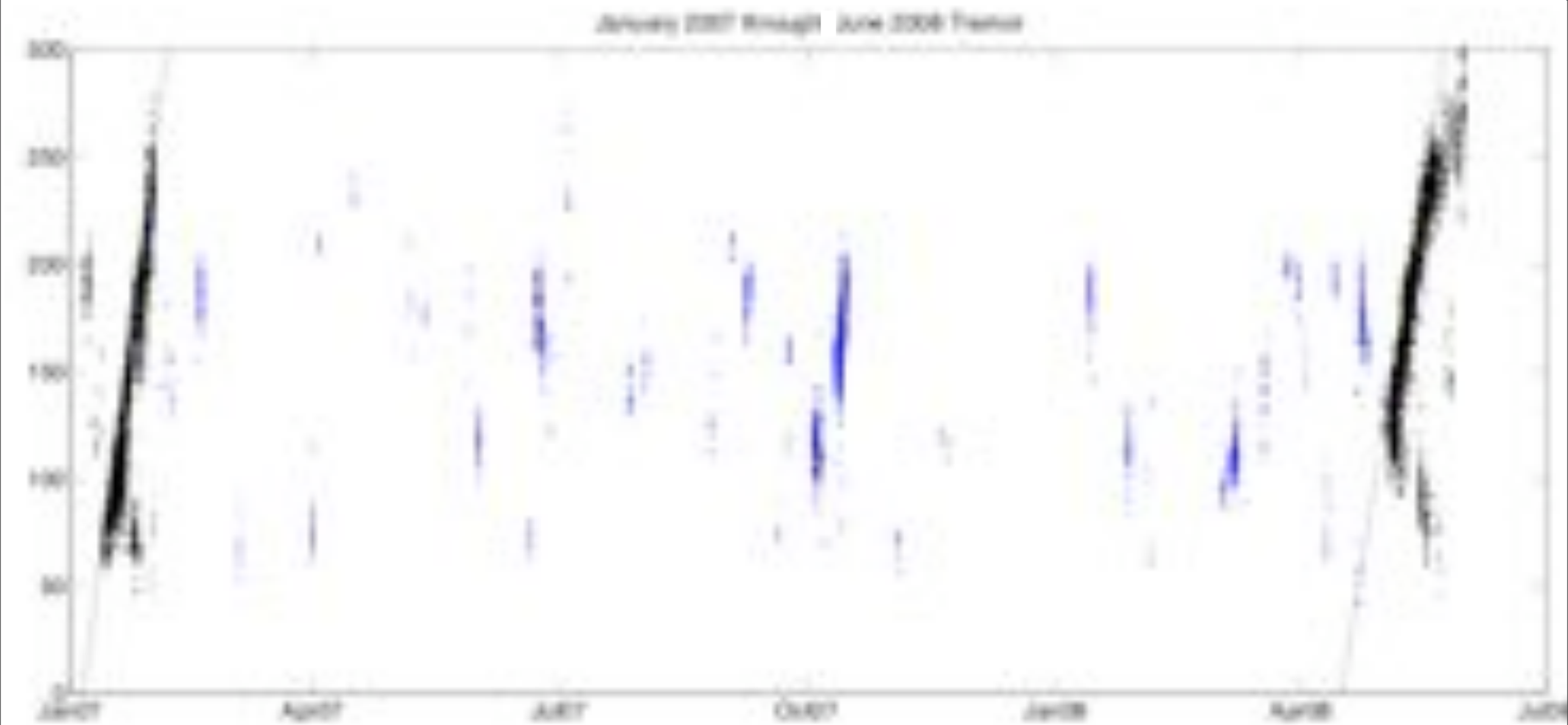
Gomberg *et al.*, 2008





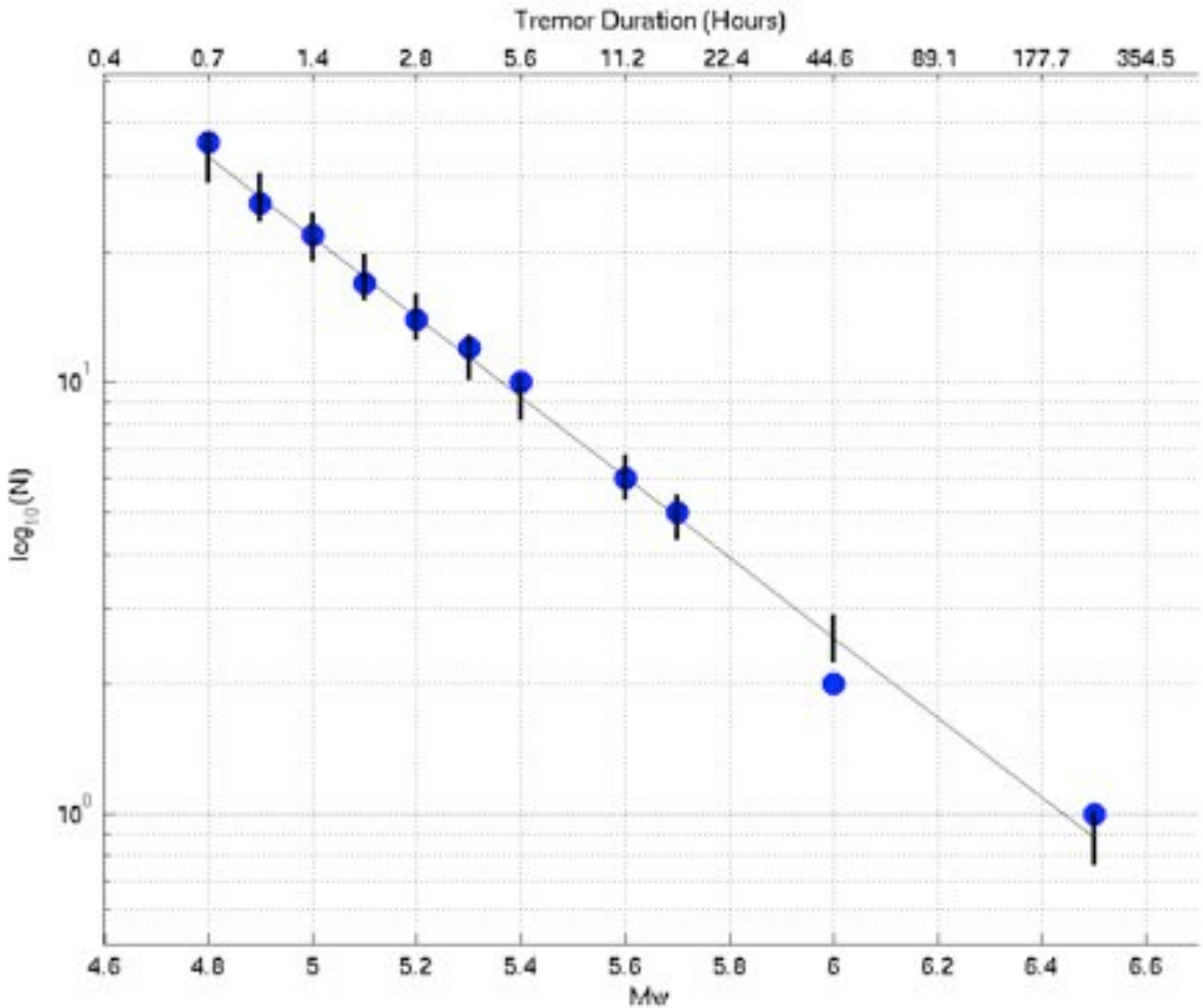
Smaller events between major ETS episodes

between two Cascadia ETS events, projected along strike



Wech *et al.*, in press, GRL

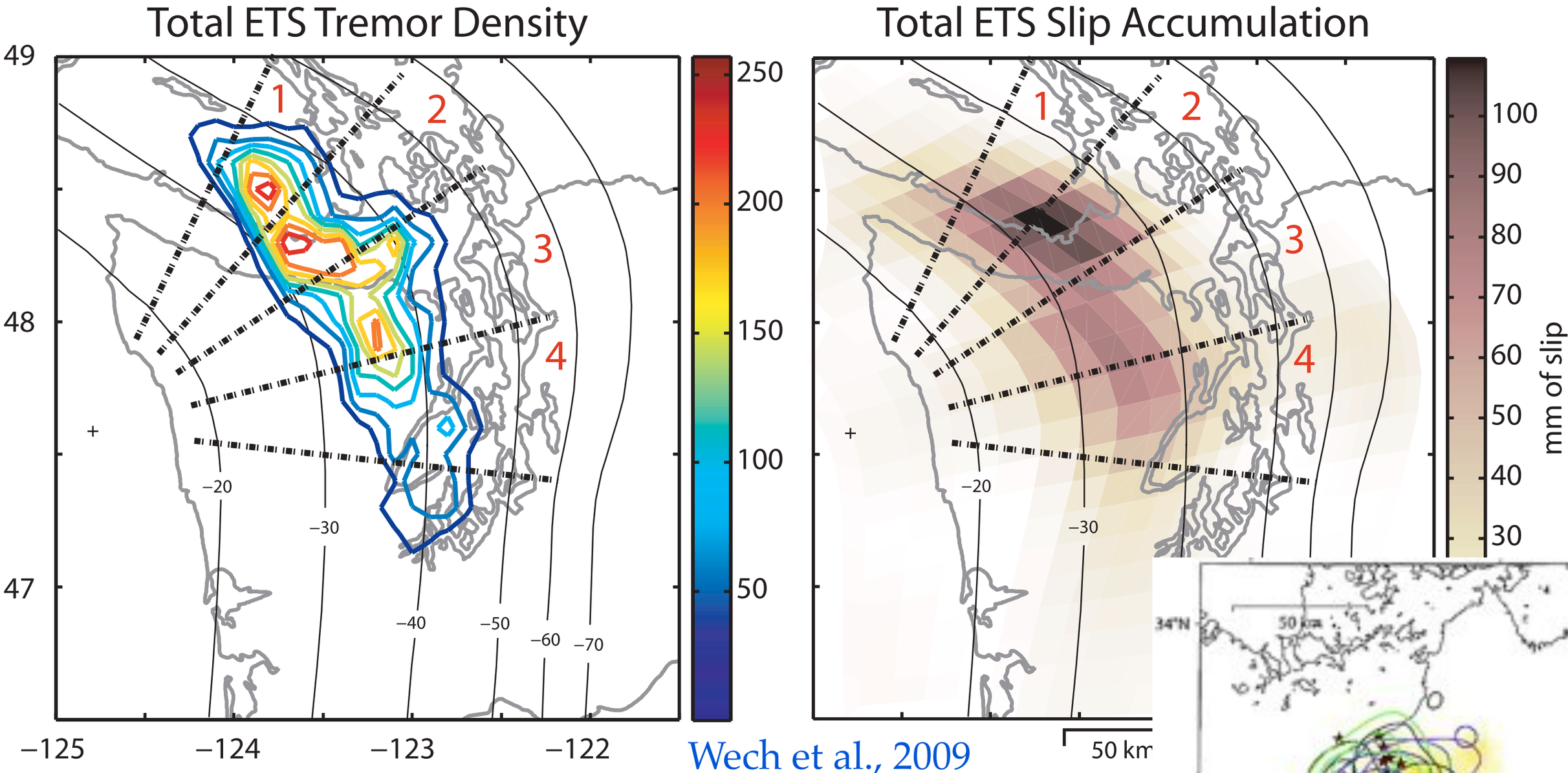
Gutenberg-Richter Power-Law Distribution of Tremor Swarms



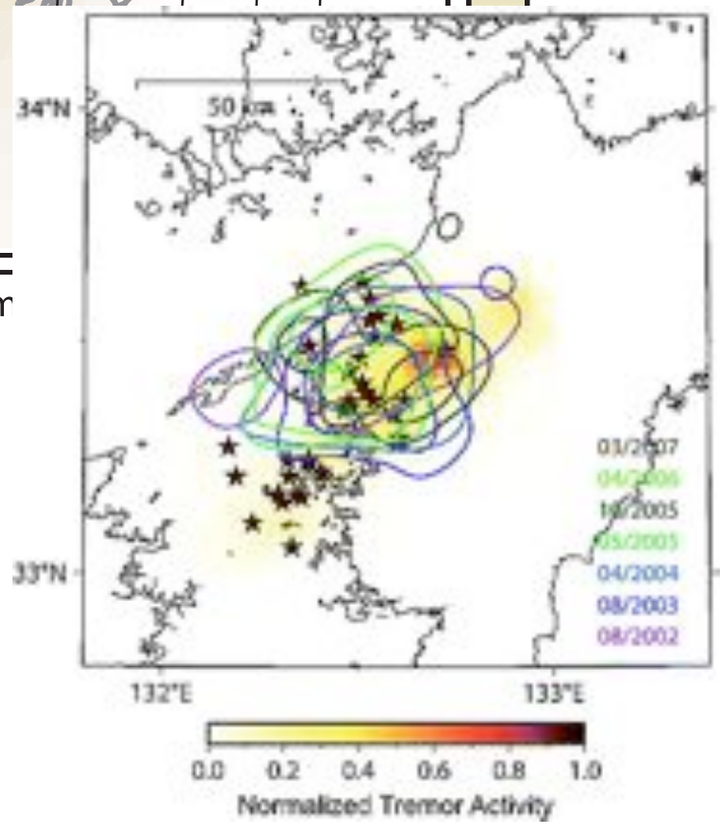
(assuming moment is proportional to duration)

Wech et al., in press, GRL

Tremor and slow slip coincide in space

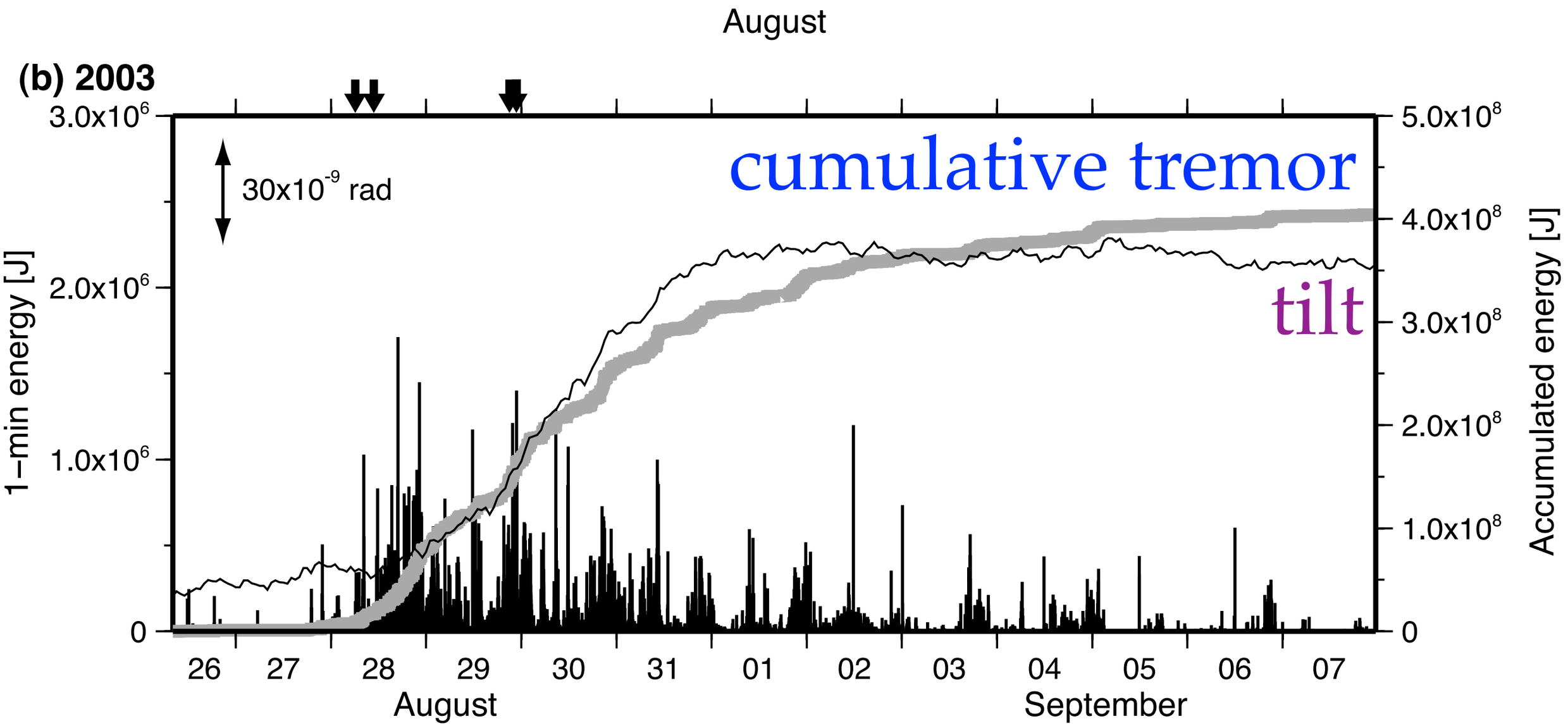


Wech et al., 2009

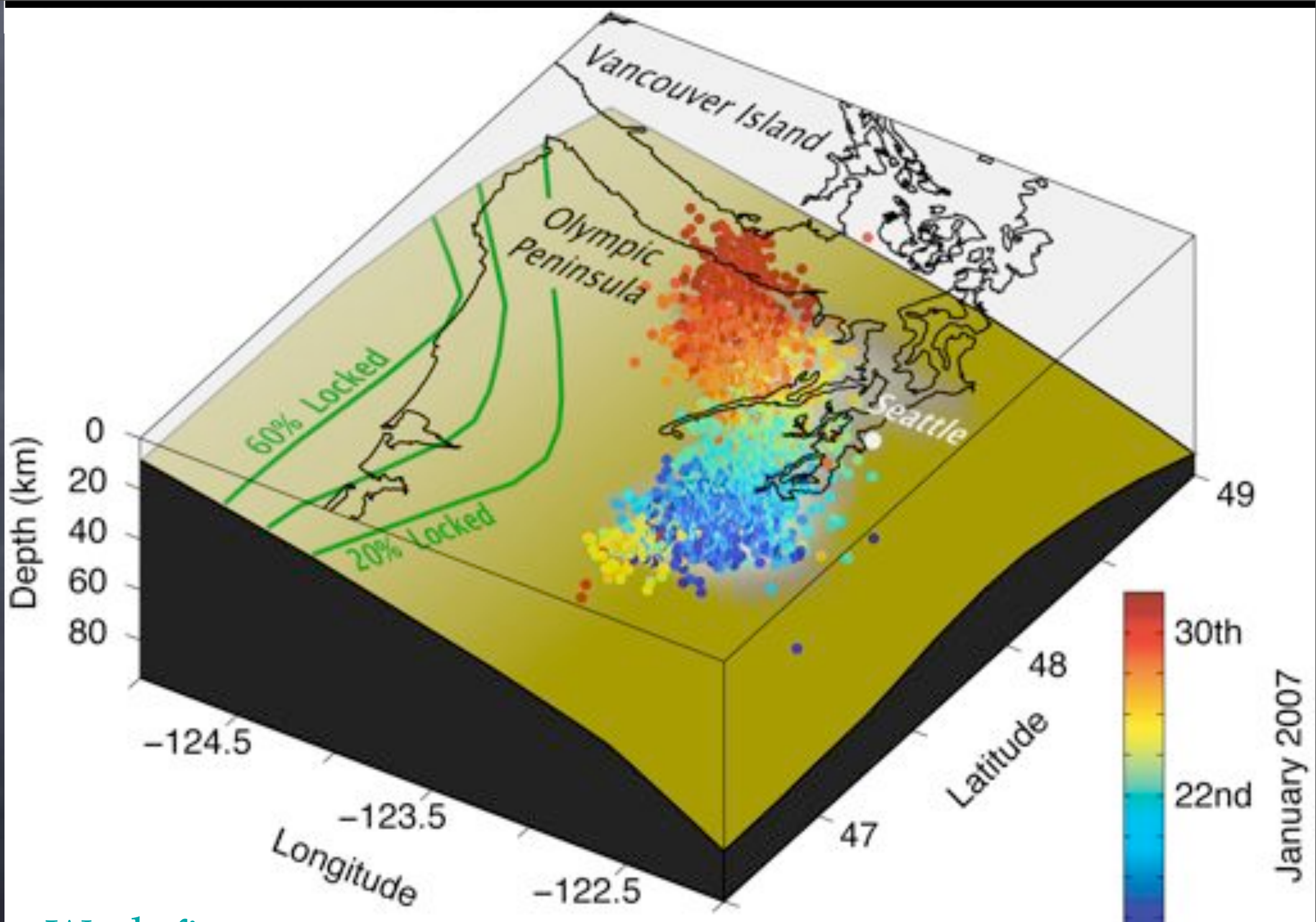


Hirose & Obara, JGR, 2010

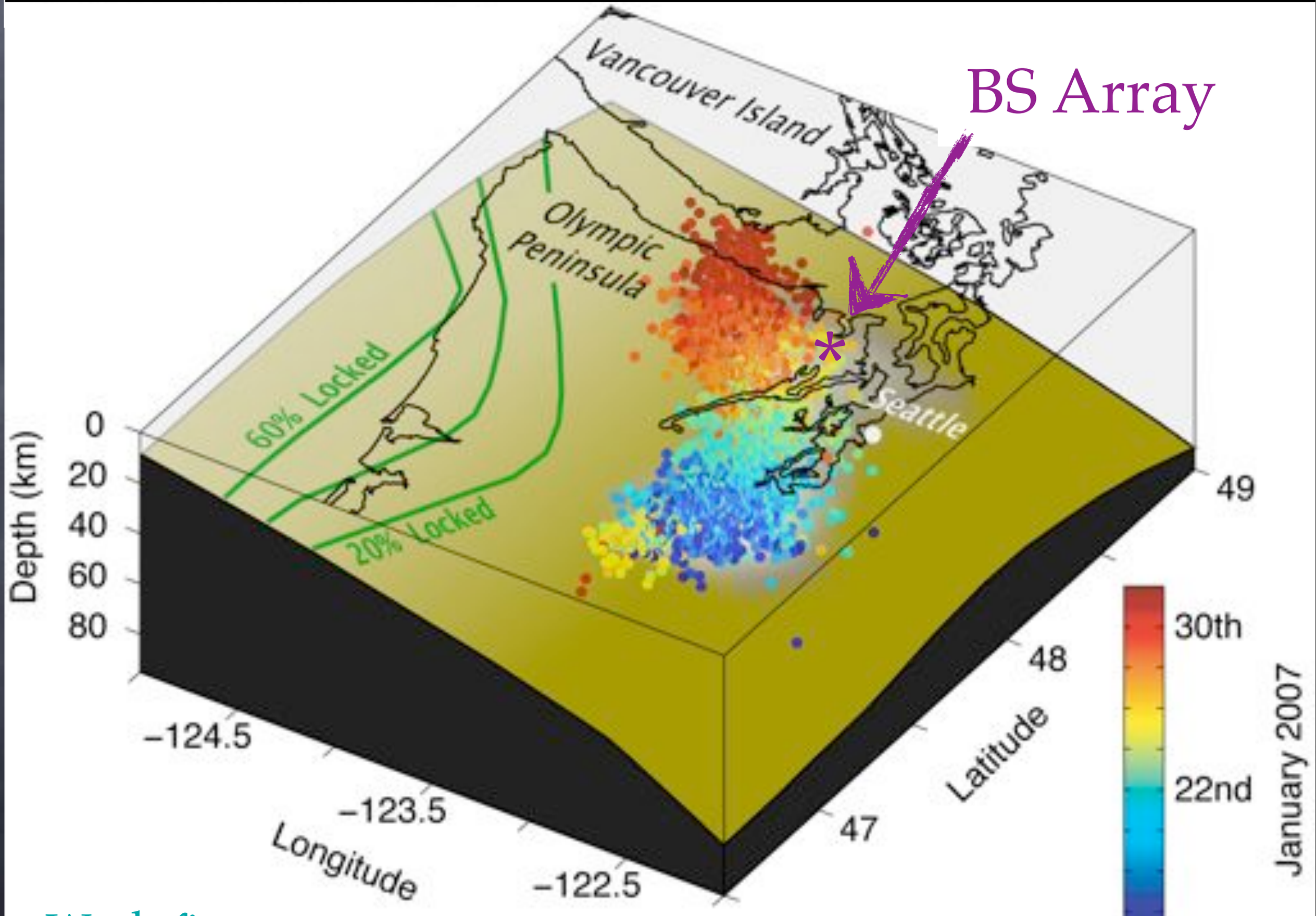
Tremor and slow slip coincide in time



Maeda & Obara, 2009


Vancouver Island
Olympic Peninsula
60% Locked
20% Locked
Seattle
Depth (km)
0
20
40
60
80
−124.5
−123.5
−122.5
Longitude
47
48
49
Latitude
30th
22nd
14th
January 2007

Wech figure


BS Array
Vancouver Island
Olympic Peninsula
60% Locked
20% Locked
Seattle
*
Depth (km)
0
20
40
60
80
−124.5
−123.5
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Longitude
47
48
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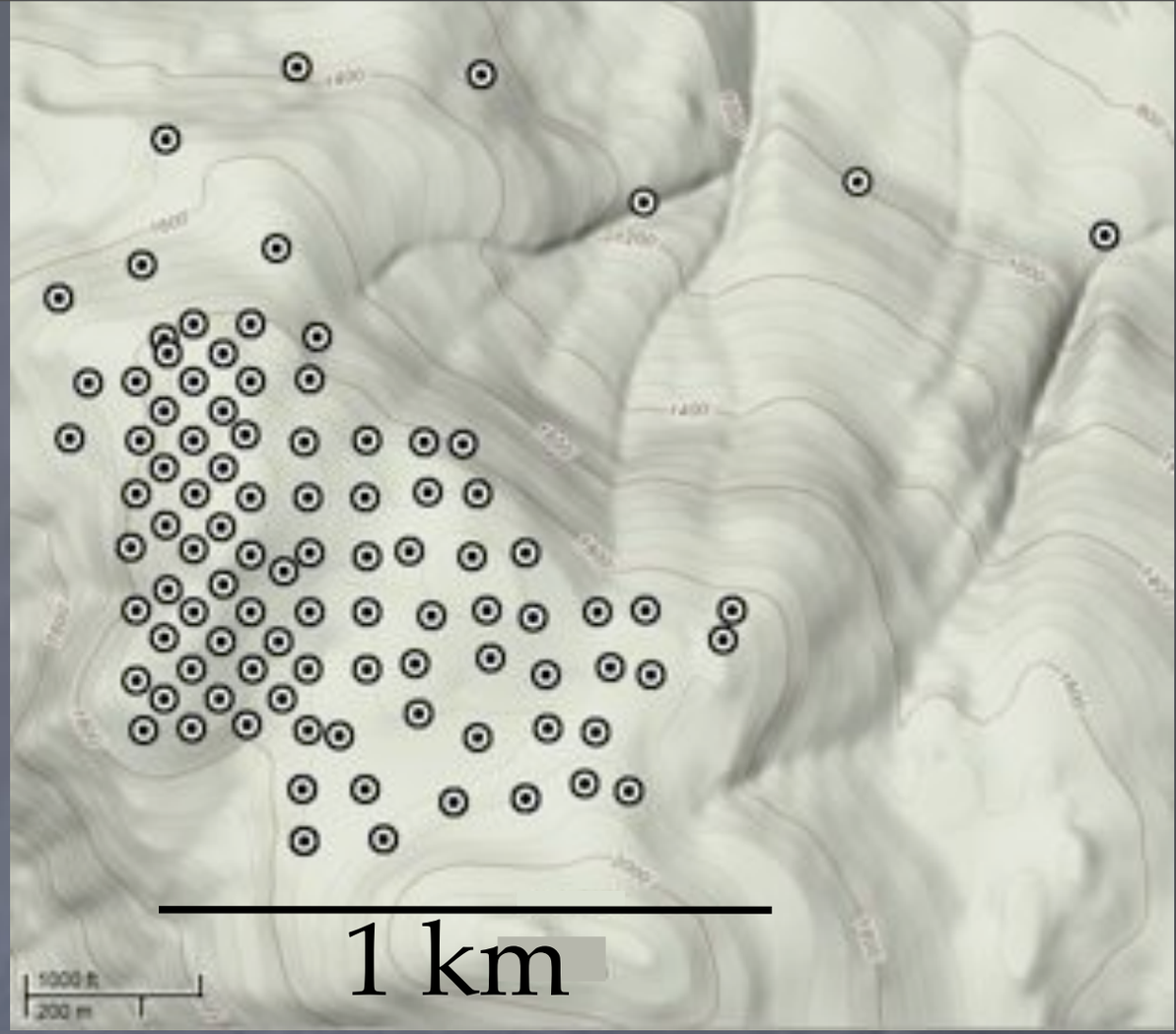
Latitude
30th
22nd
14th
January 2007

Wech figure

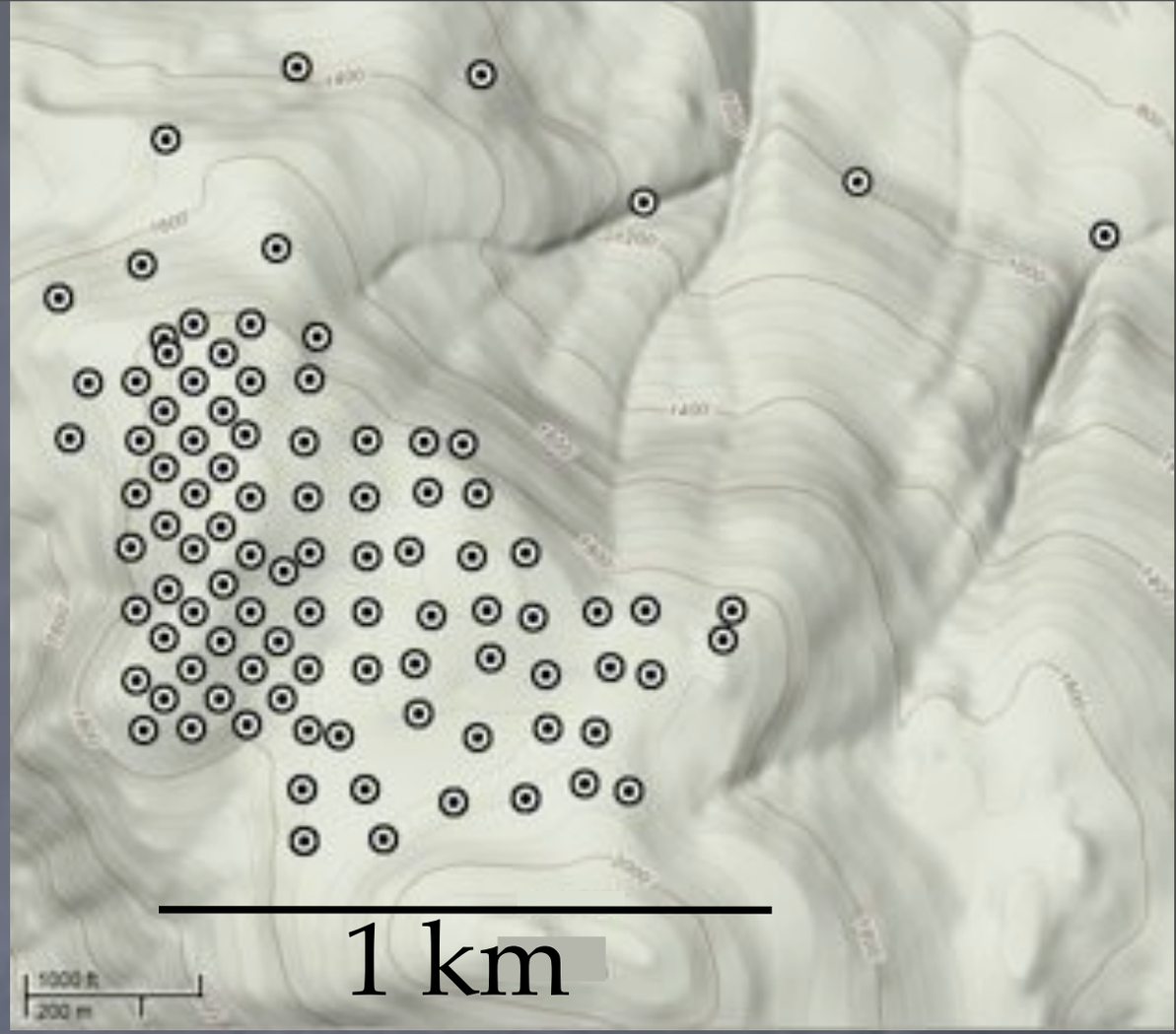
2008 dense-array pilot study



Time (days)

2008 dense-array pilot study

84 sensors in a km^2,



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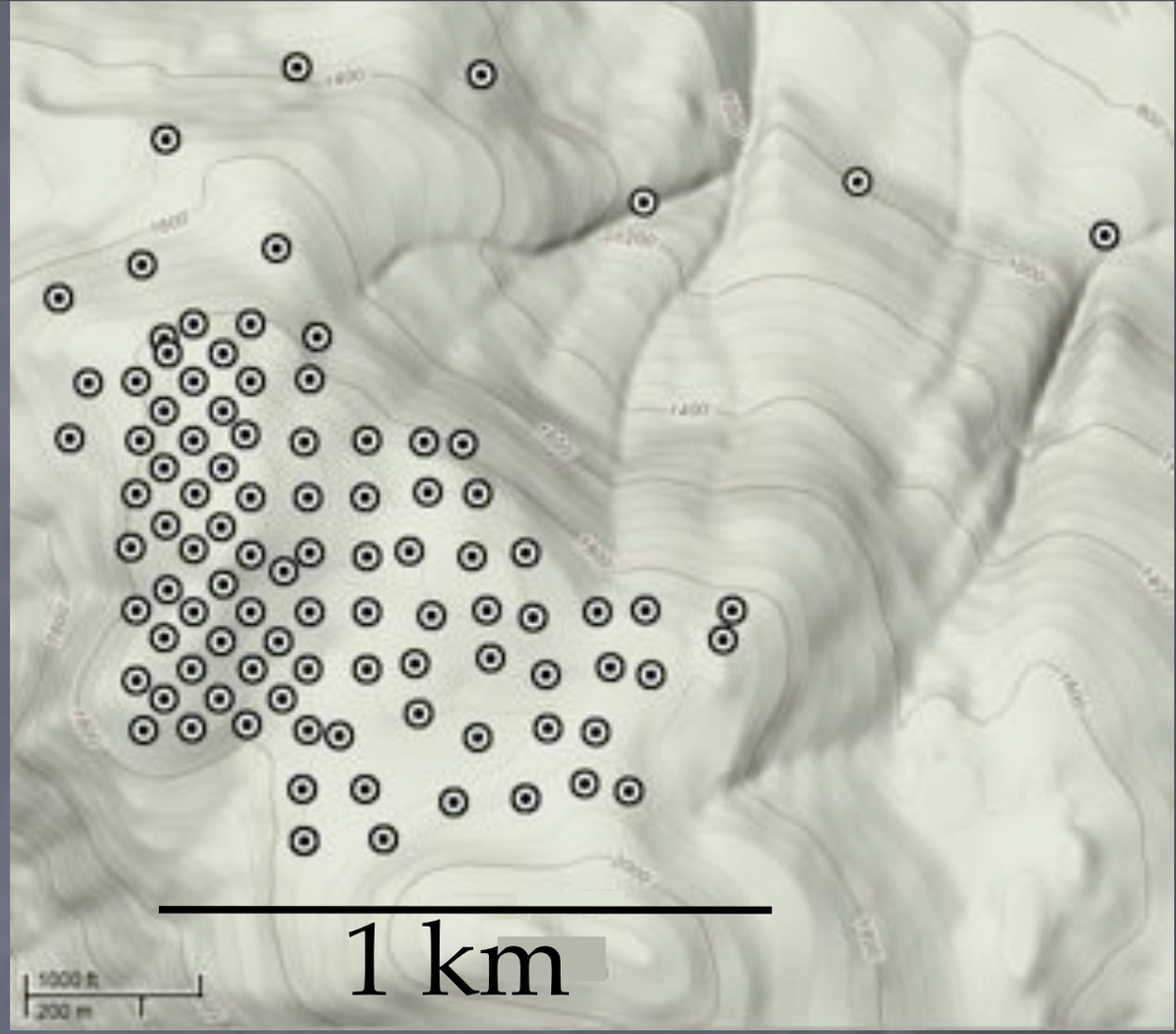

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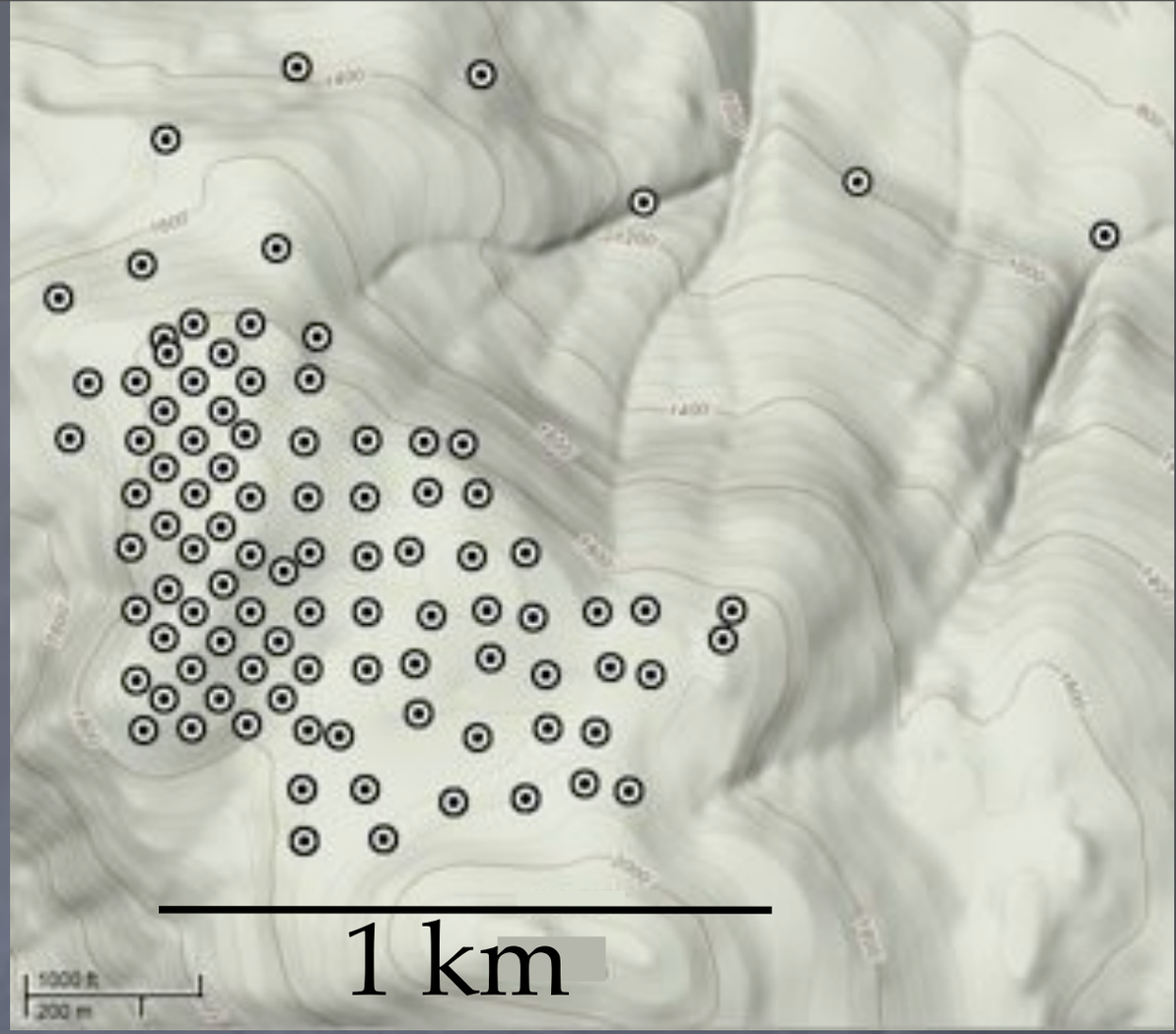

Time (days)

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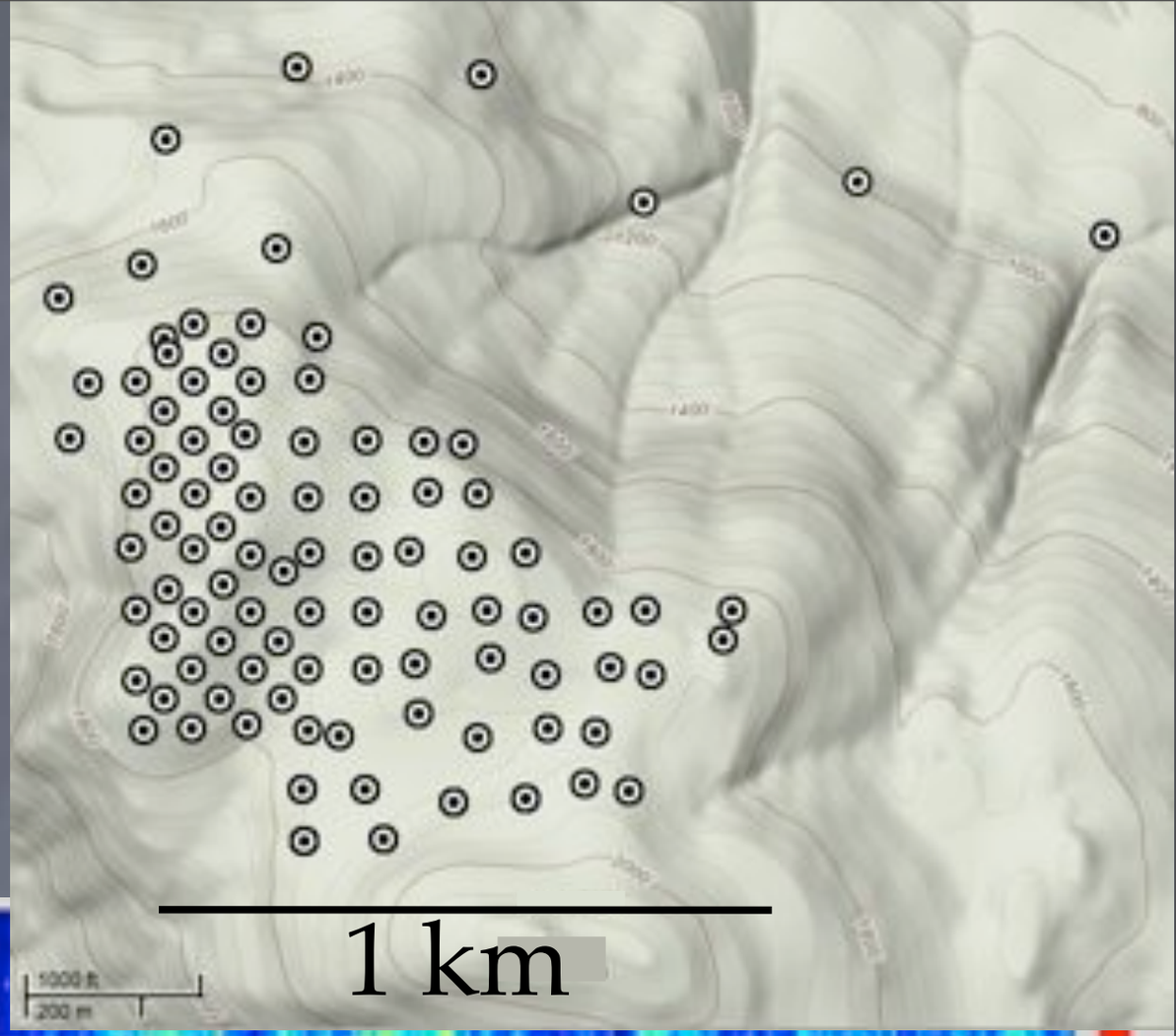
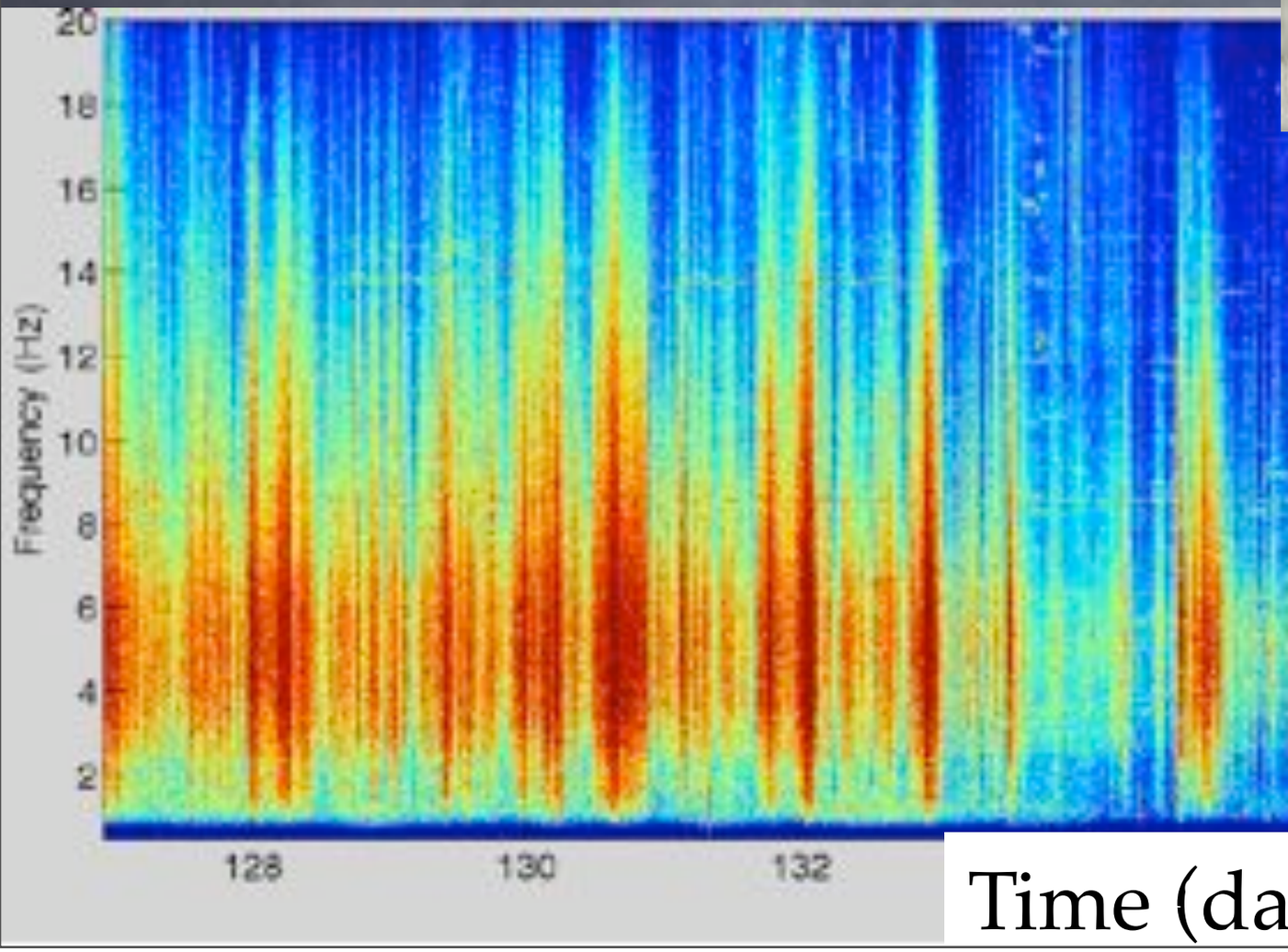
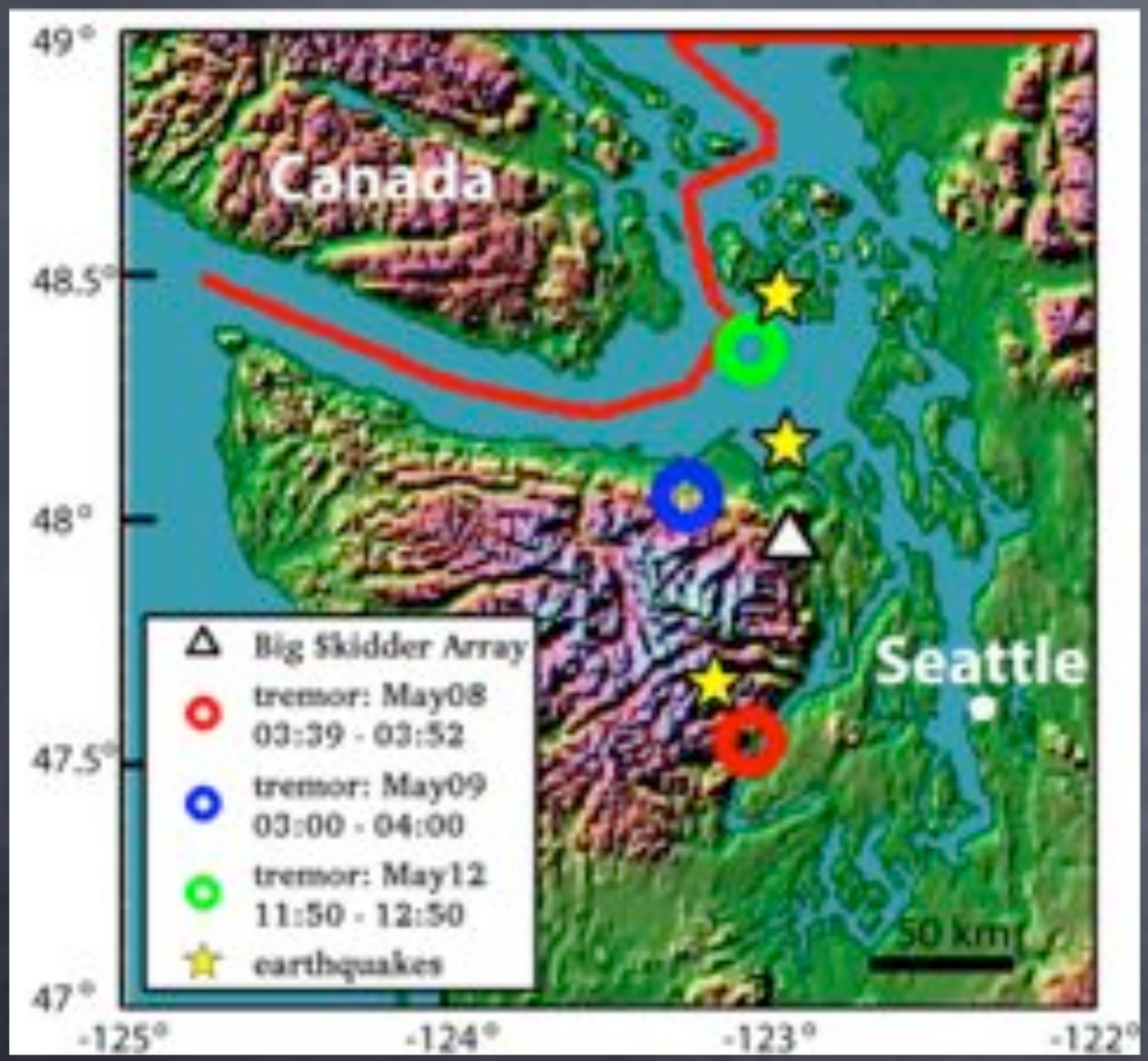




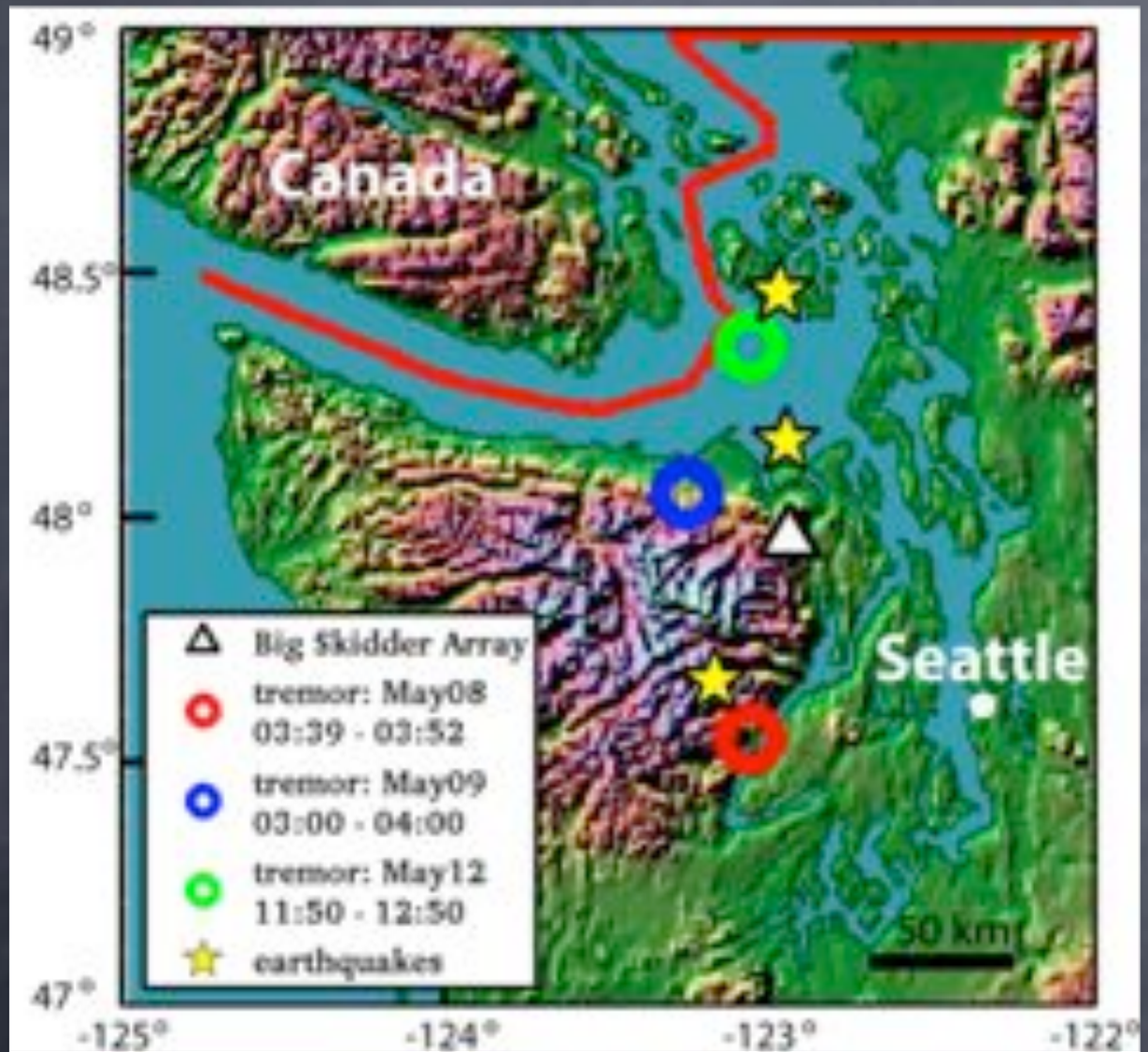
Time (days)

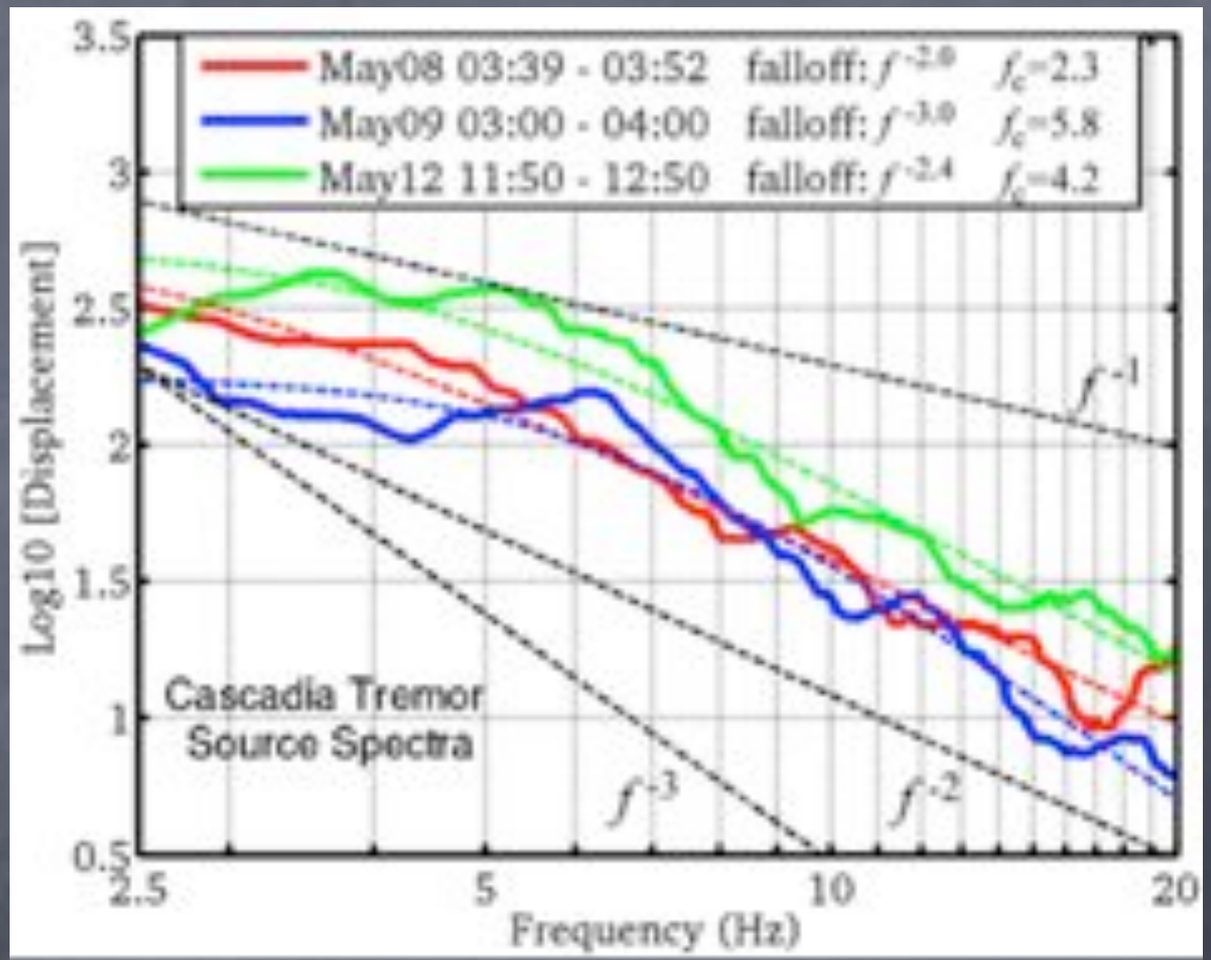
Tremor source spectra not so simple



Zhang, Gerstoft, Shearer, Yao, Vidale, Houston, Ghosh, *in prep*

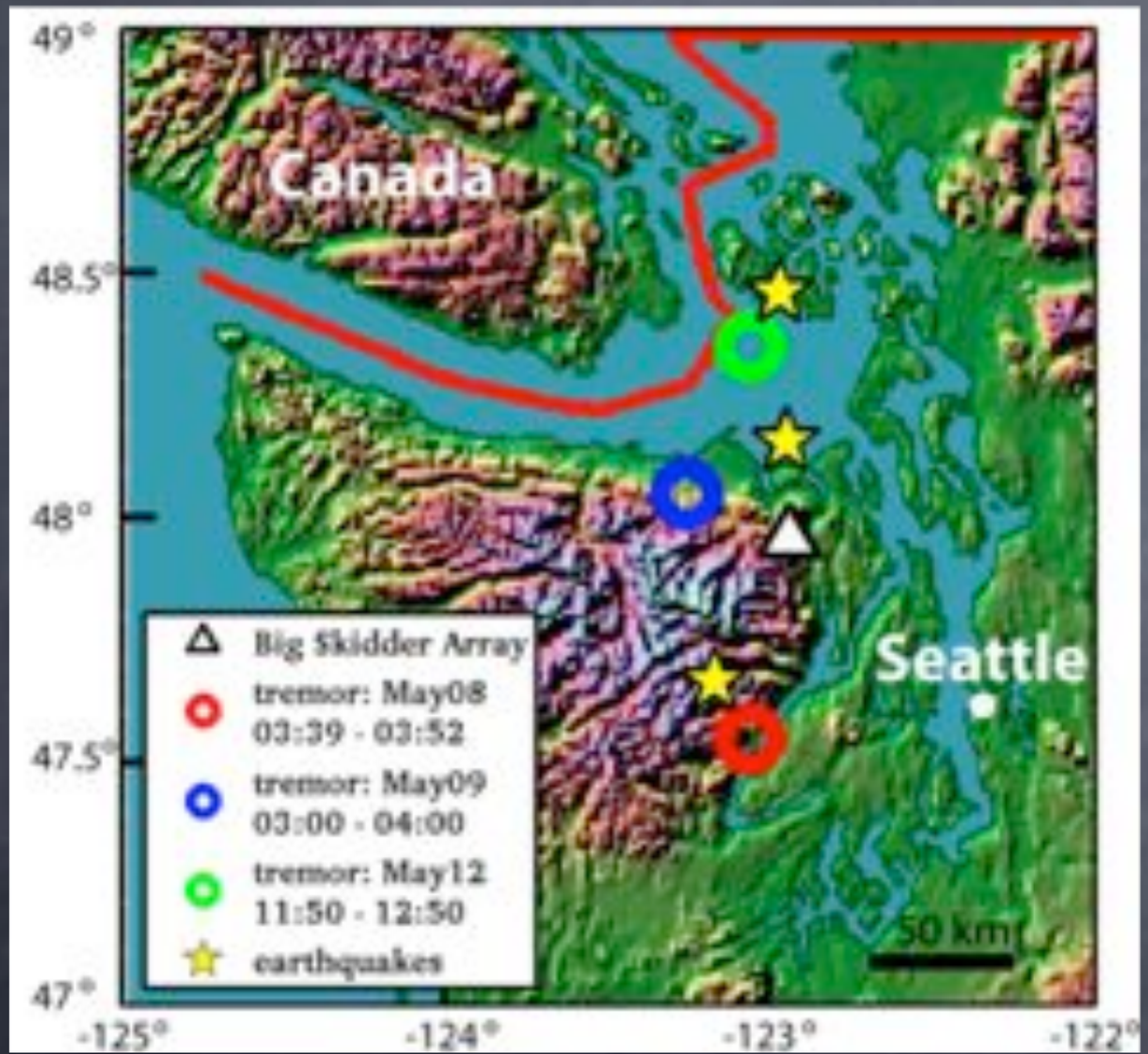
Tremor source spectra not so simple

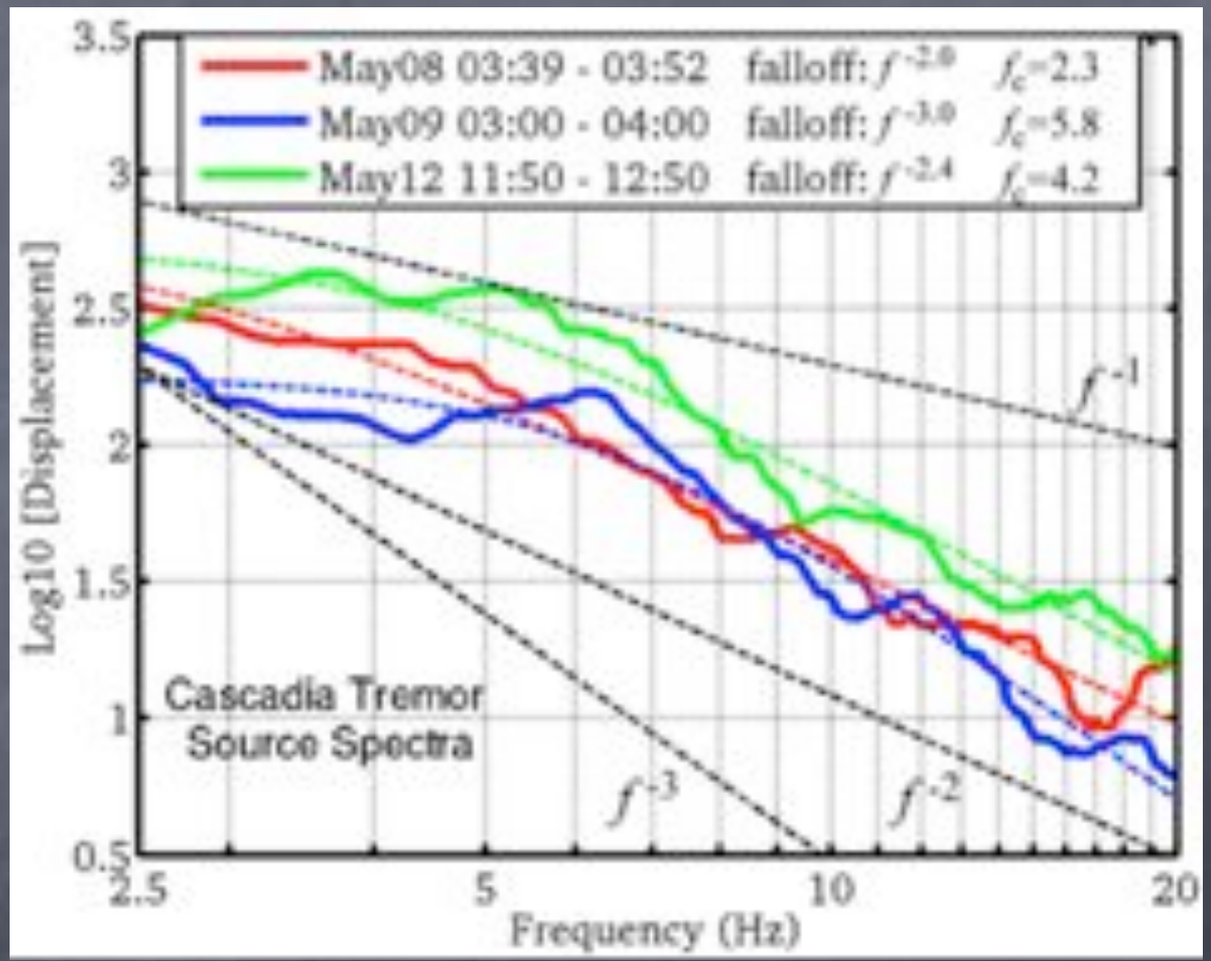




Zhang, Gerstoft, Shearer, Yao, Vidale, Houston, Ghosh, *in prep*

Tremor source spectra not so simple



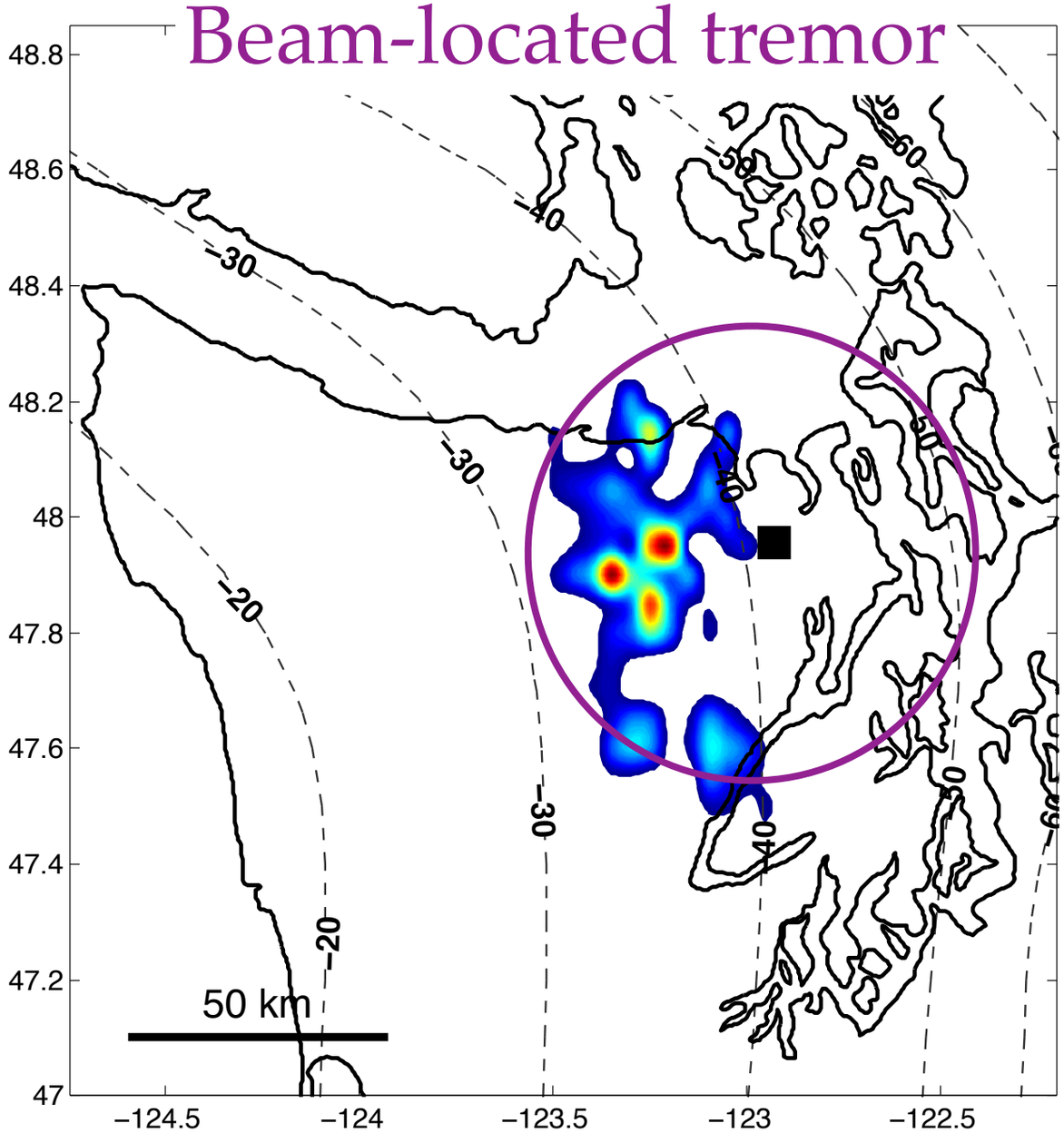


No ultraviolet catastrophe, but what's going on?

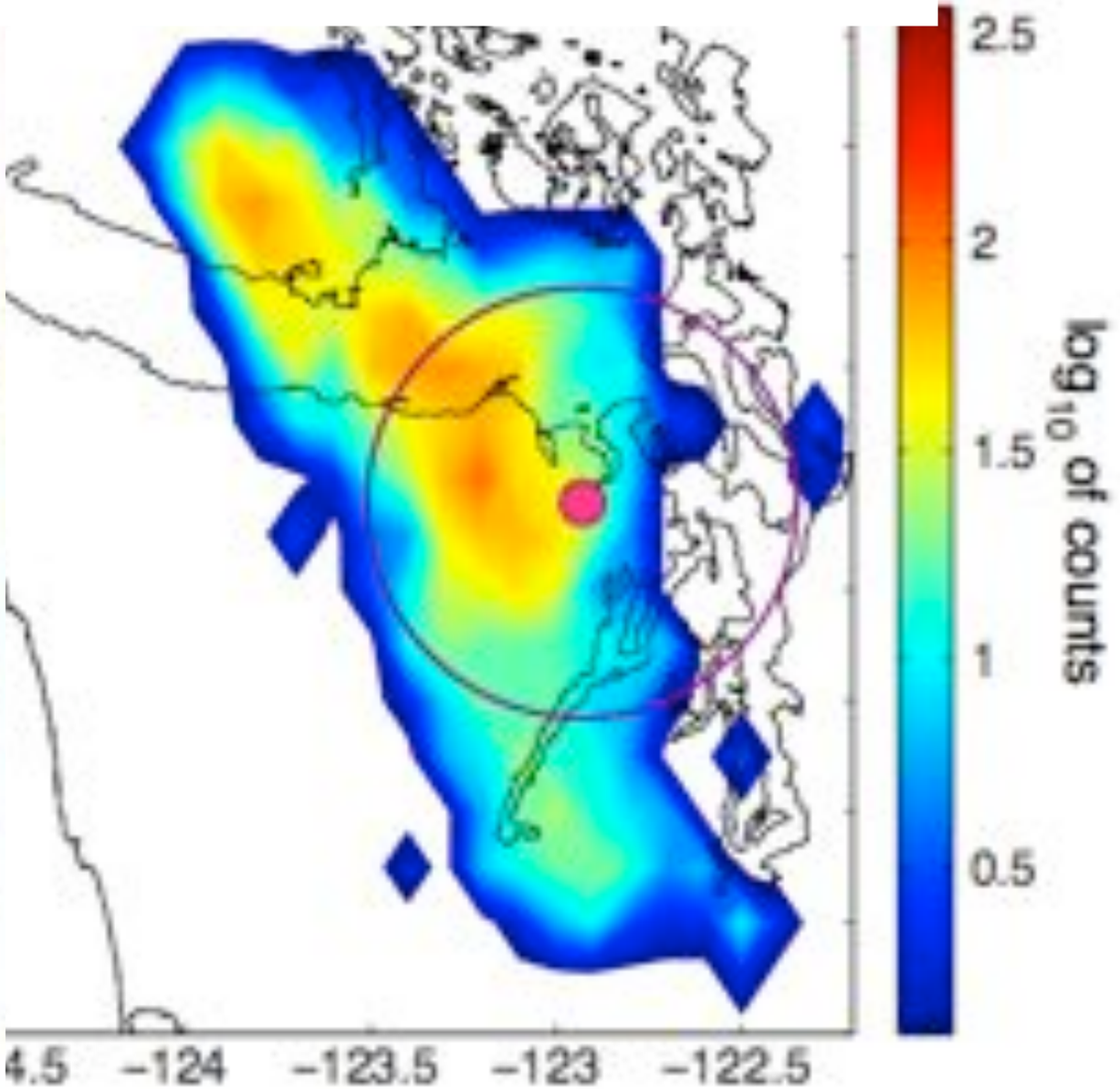
Zhang, Gerstoft, Shearer, Yao, Vidale, Houston, Ghosh, *in prep*

Tremor more irregular than previously mapped?

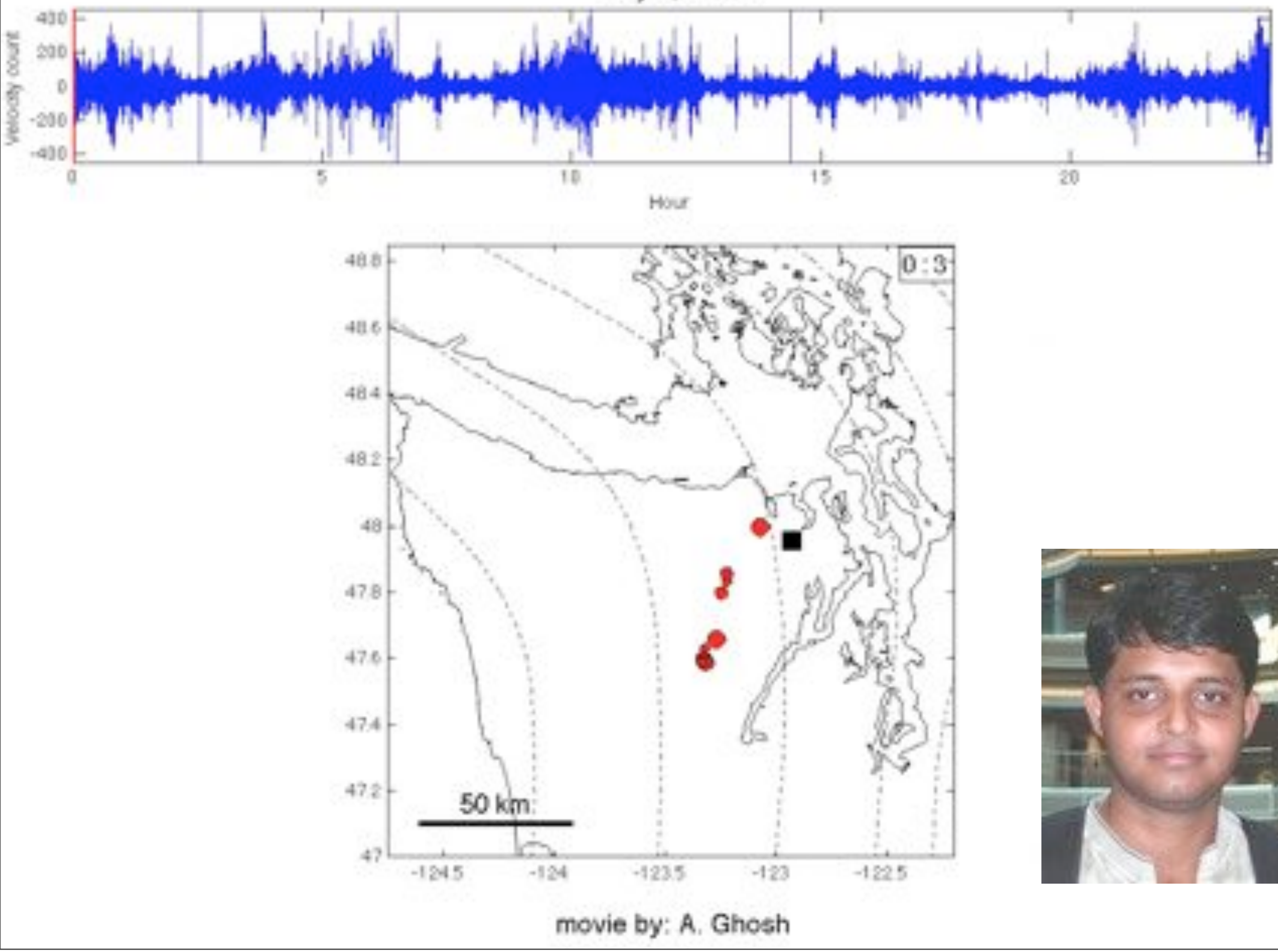
Beam-located tremor

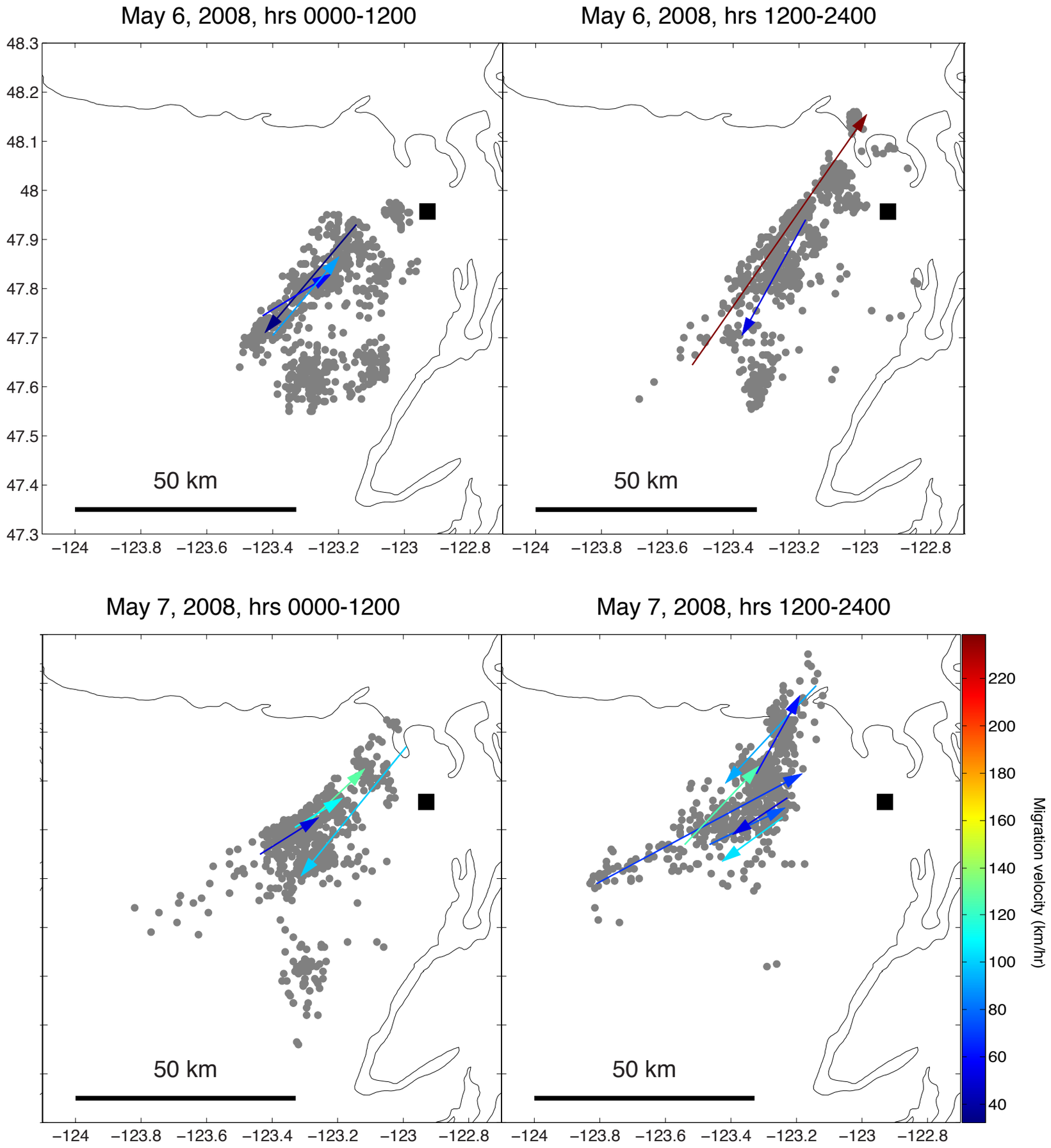


Cross-correlation tremor



Ghosh et al., 2009

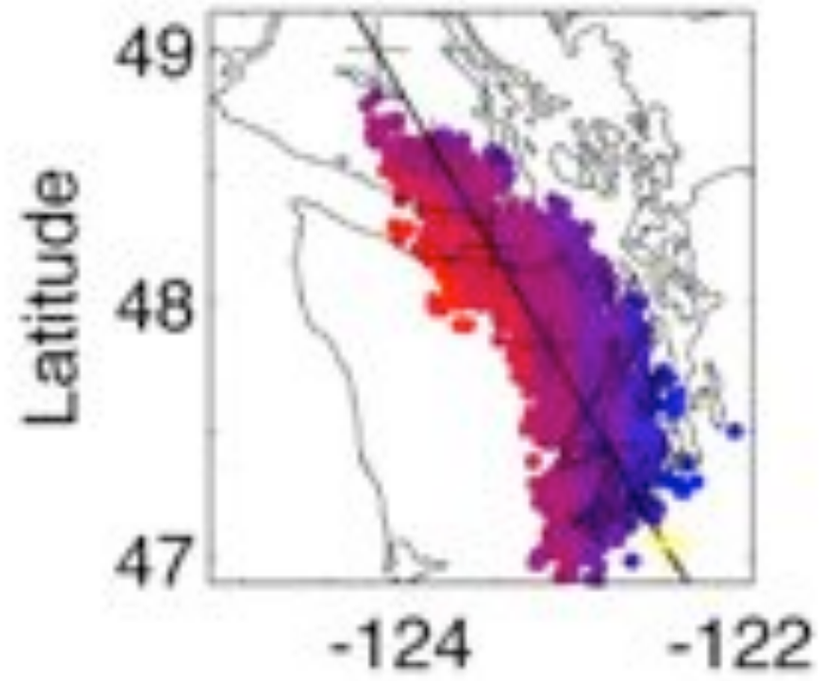

May 7, 2008
Velocity count
Hour
0 : 3
50 km
-124.5
-124
-123.5
-123
-122.5
48.8
48.6
48.4
48.2
48
47.8
47.6
47.4
47.2
47
movie by: A. Ghosh

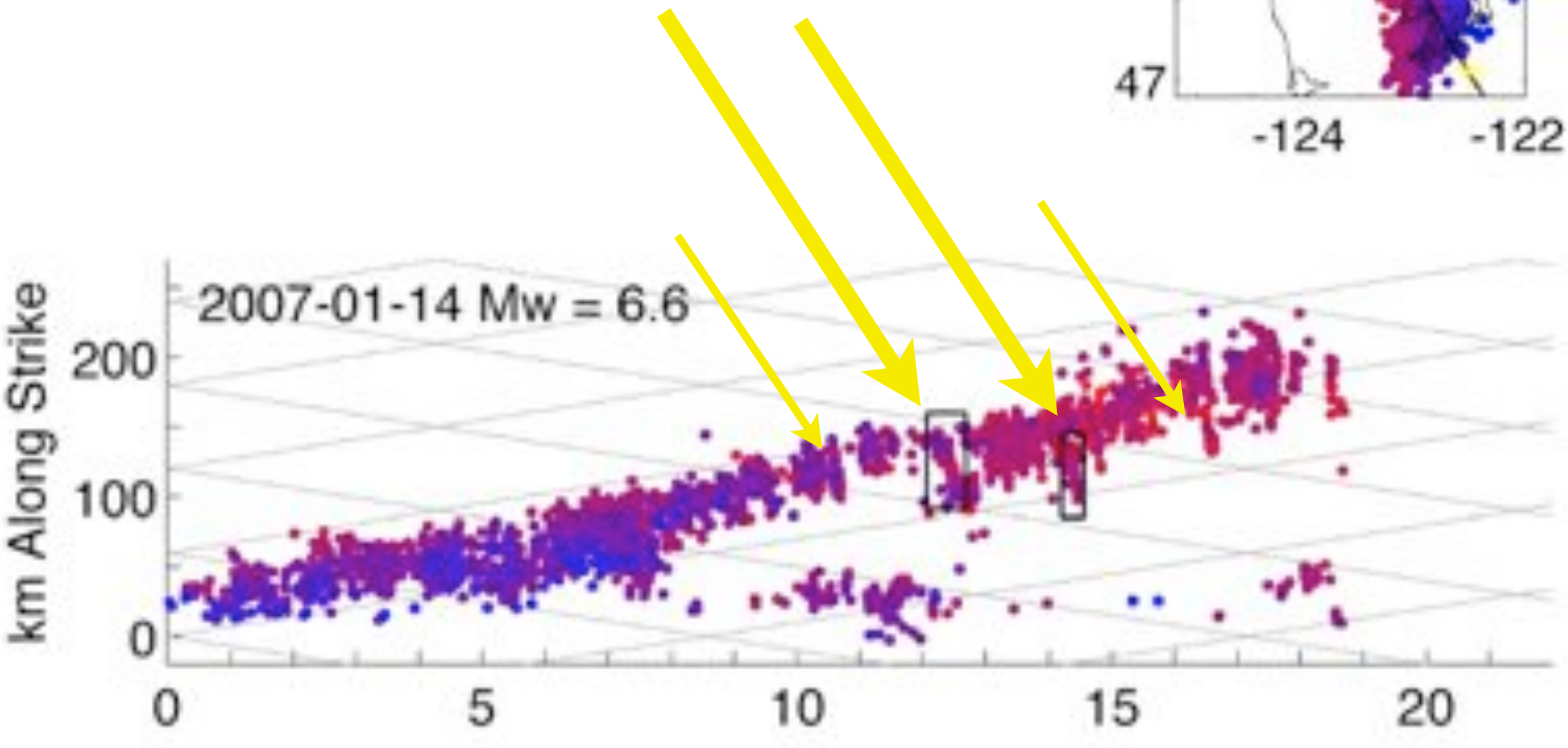


Notable tremor streaks

Ghosh *et al.*, G3, in revision

RTR's - Rapid Tremor Reversals

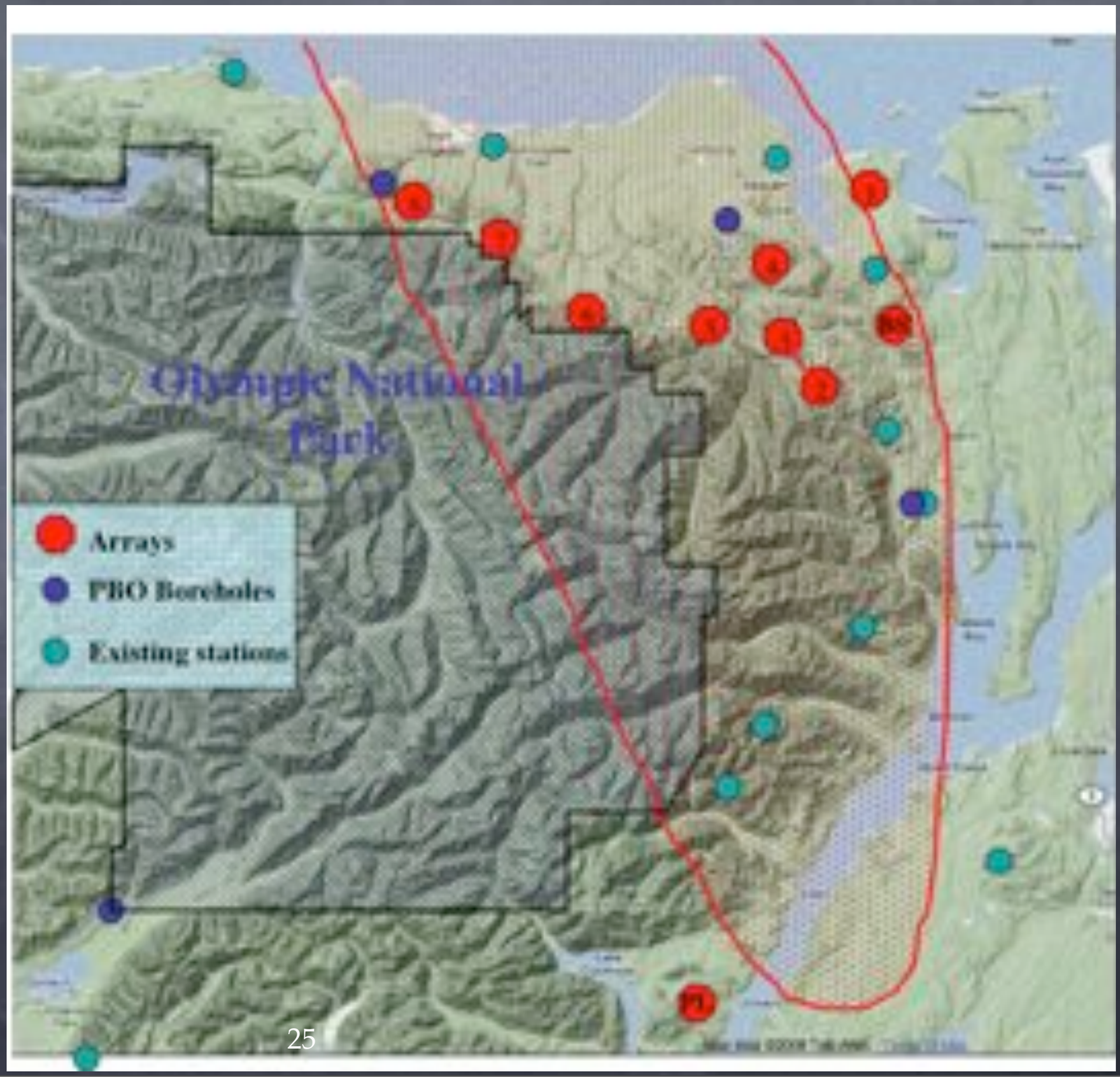




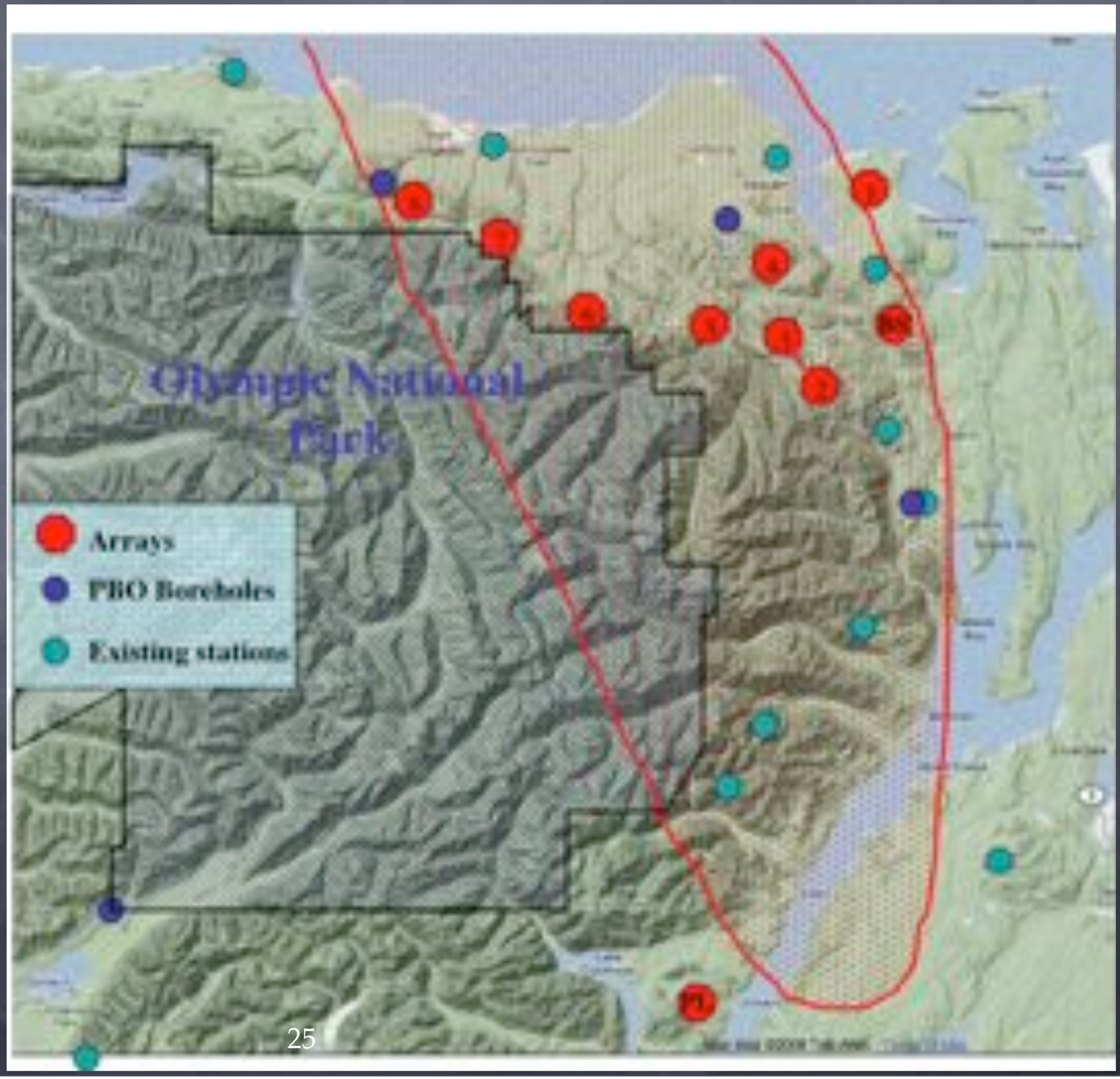
Houston, Delbridge, *et al.*, in review

Array of Arrays UW EarthScope Project

- 8 arrays
  - 10+ 3-comp SPs
  - 10 SP verticals
- Summer 2009
  - (missed it)
- Summer 2010
  - (got it)
- maybe more.



Array of Arrays UW EarthScope Project

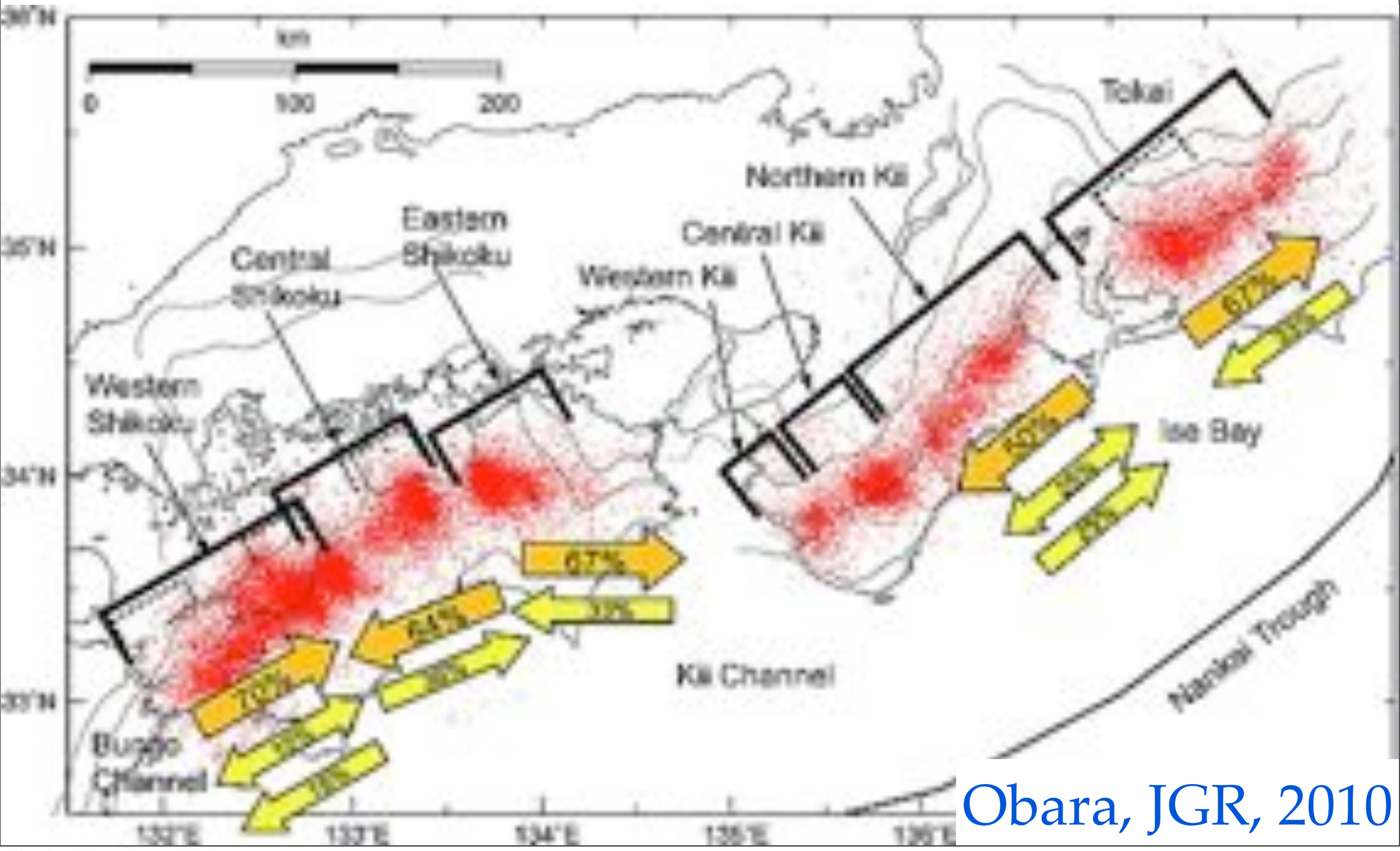


Tremor and locked zone

Ide *et al.*, 2007

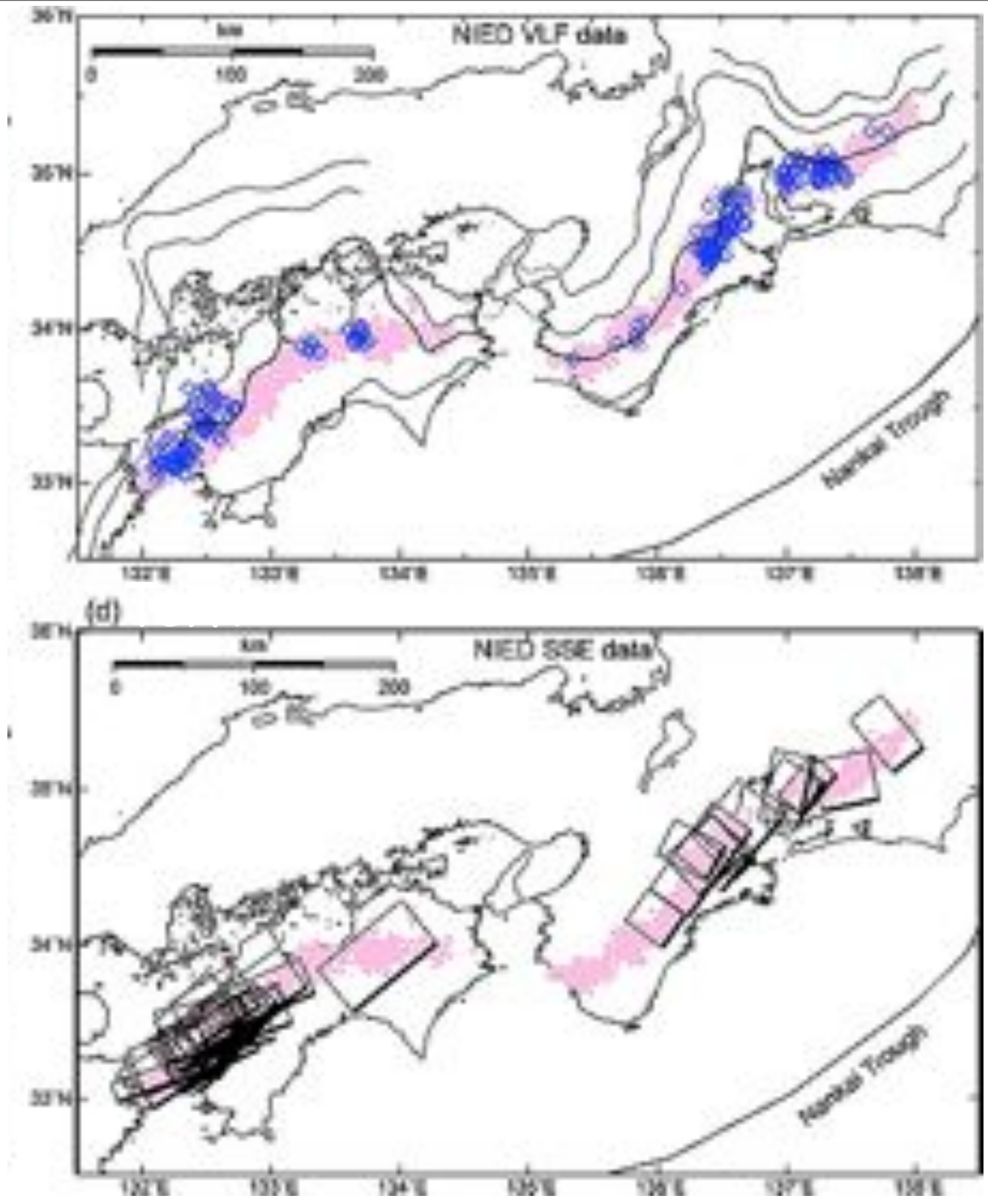
Obara, JGR, 2010

Characteristic migrations



Obara, JGR, 2010

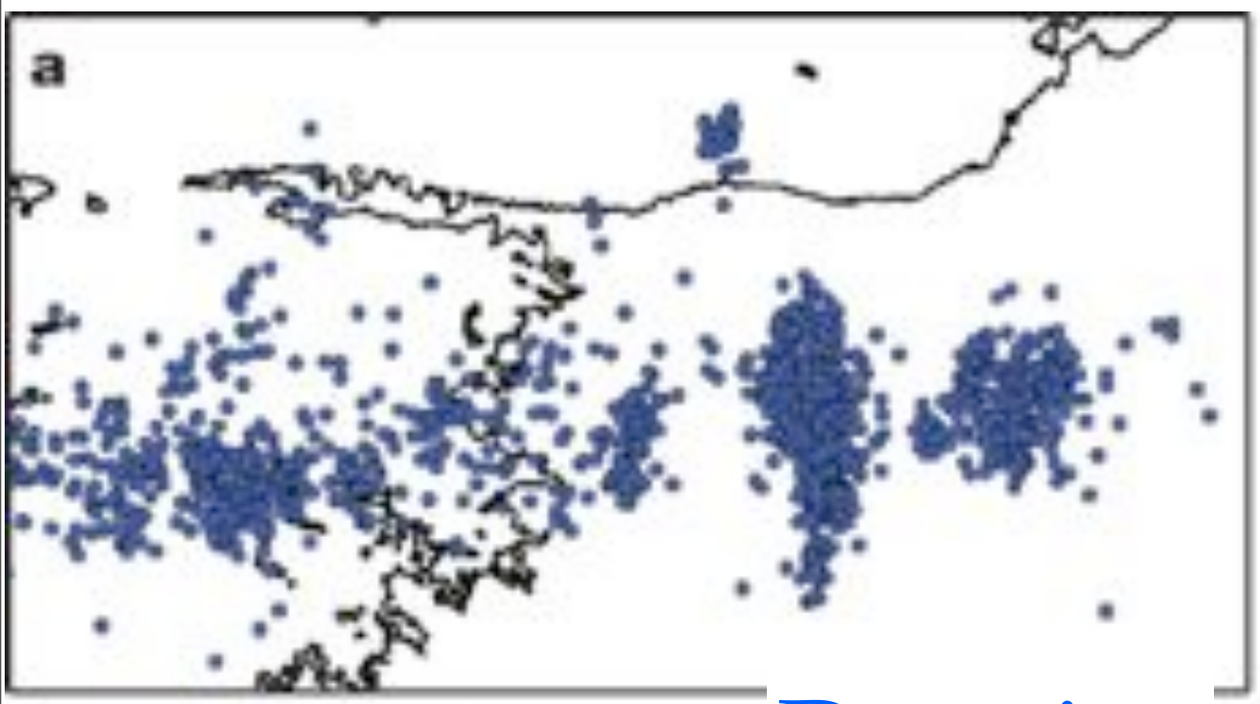
LFE vs tremor

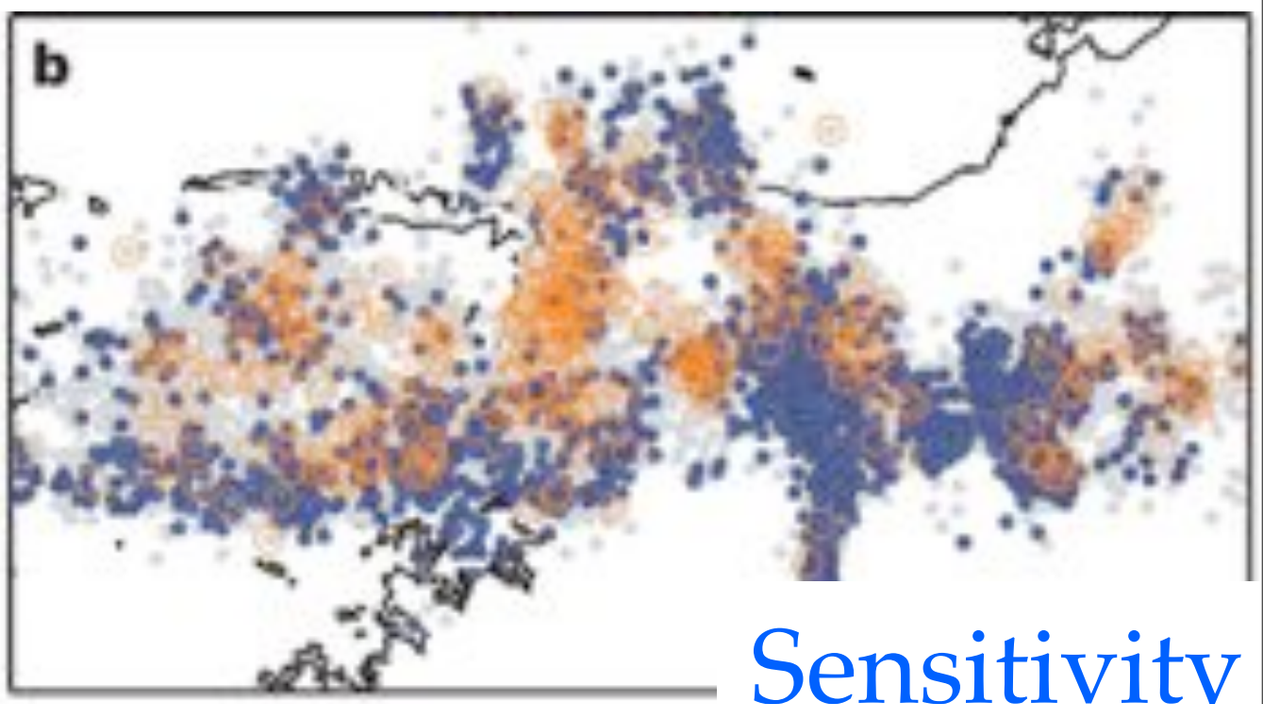


Obara, JGR, 2010

All LFEs

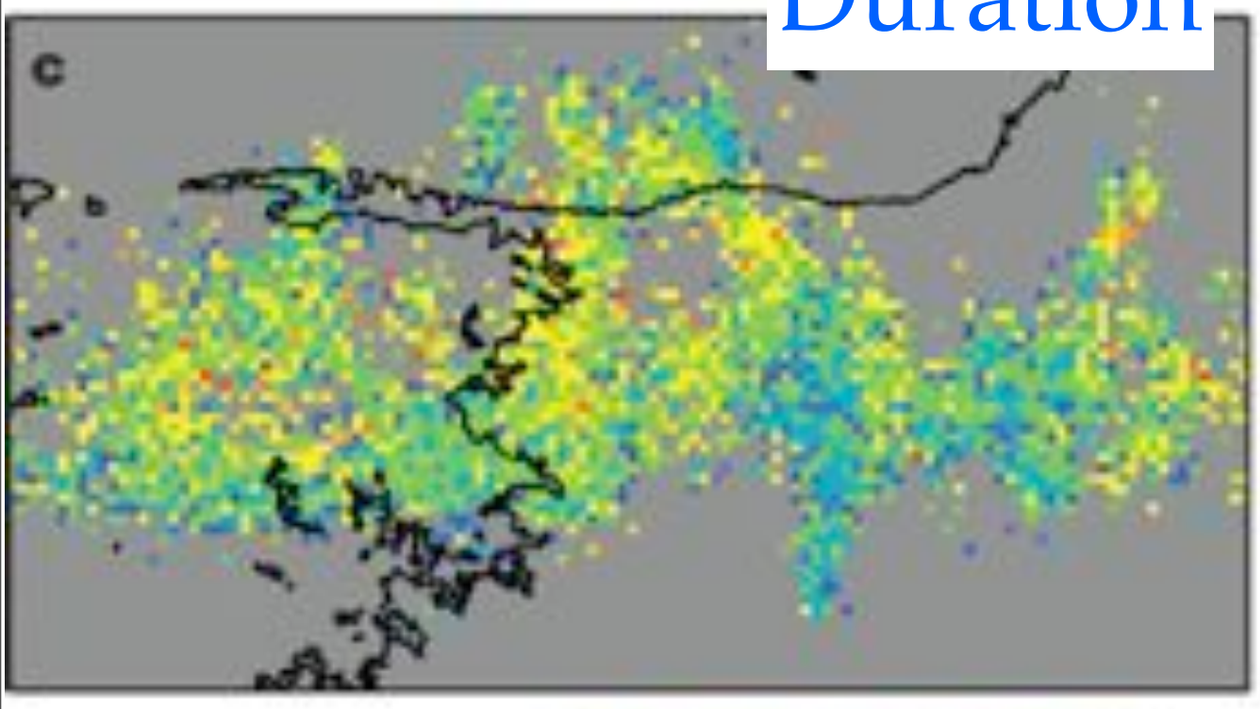
short vs long LFEs

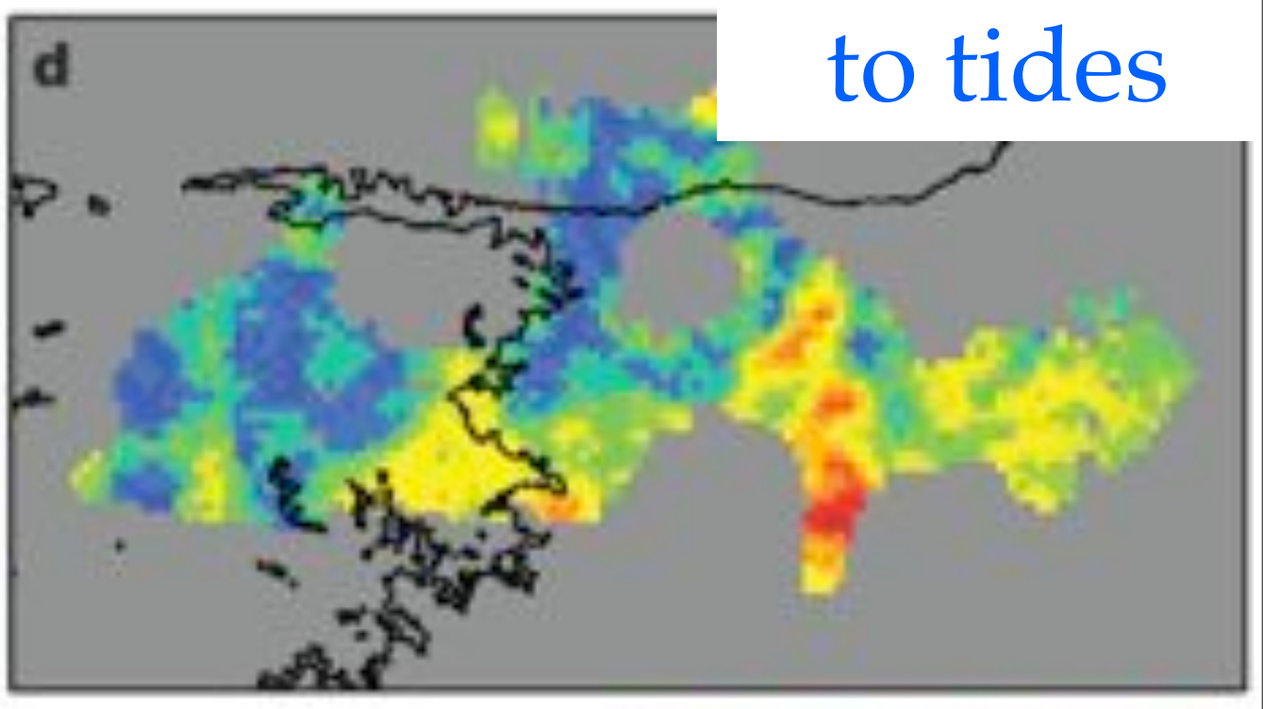


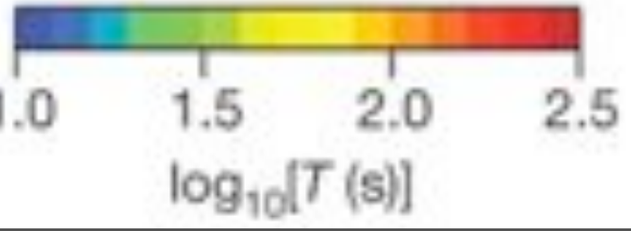


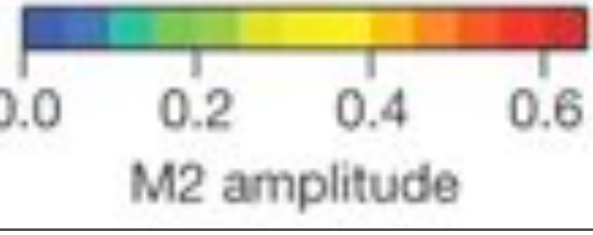
Duration

Sensitivity to tides



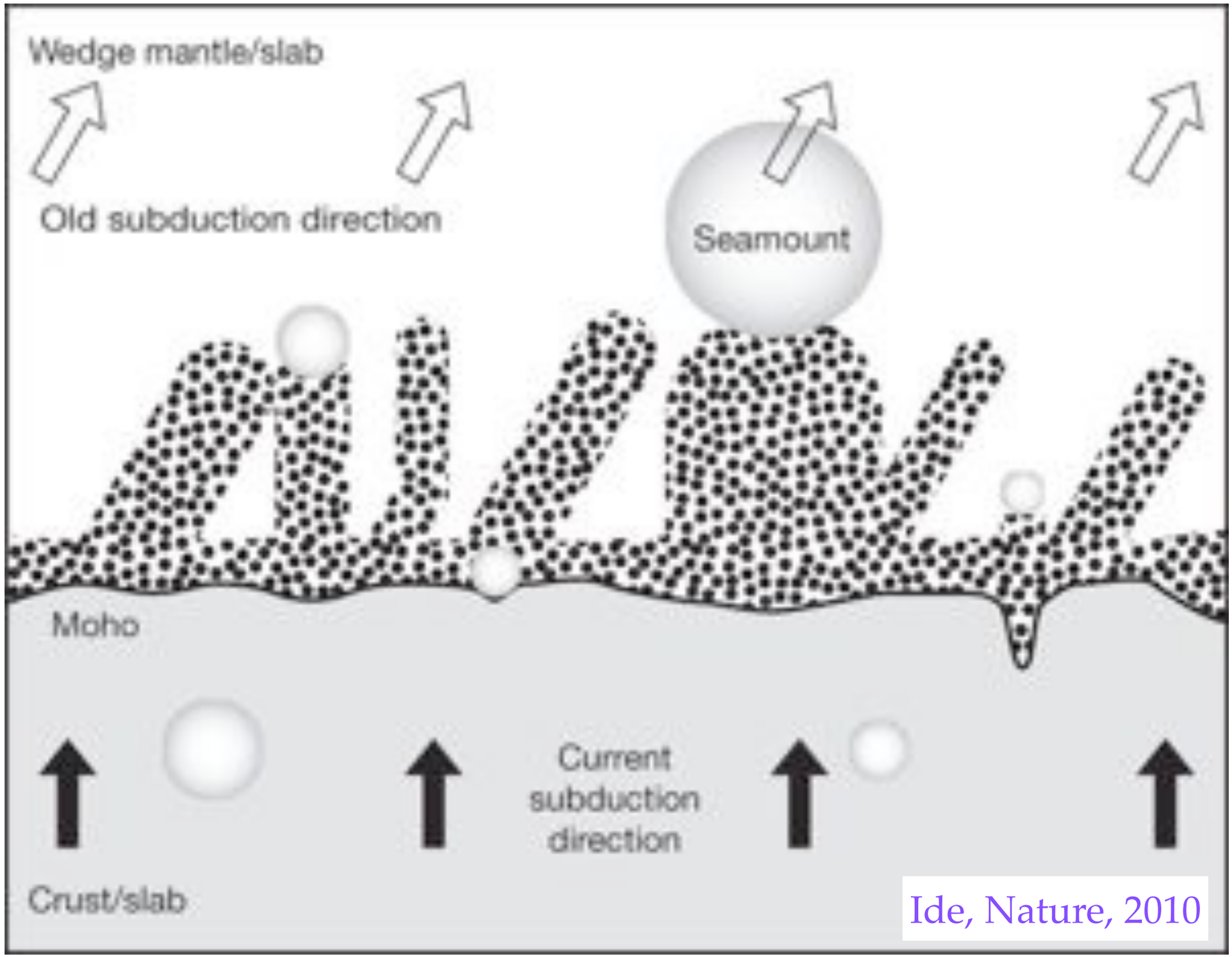






Ide, Nature, 2010

Tremor stripes vs geology

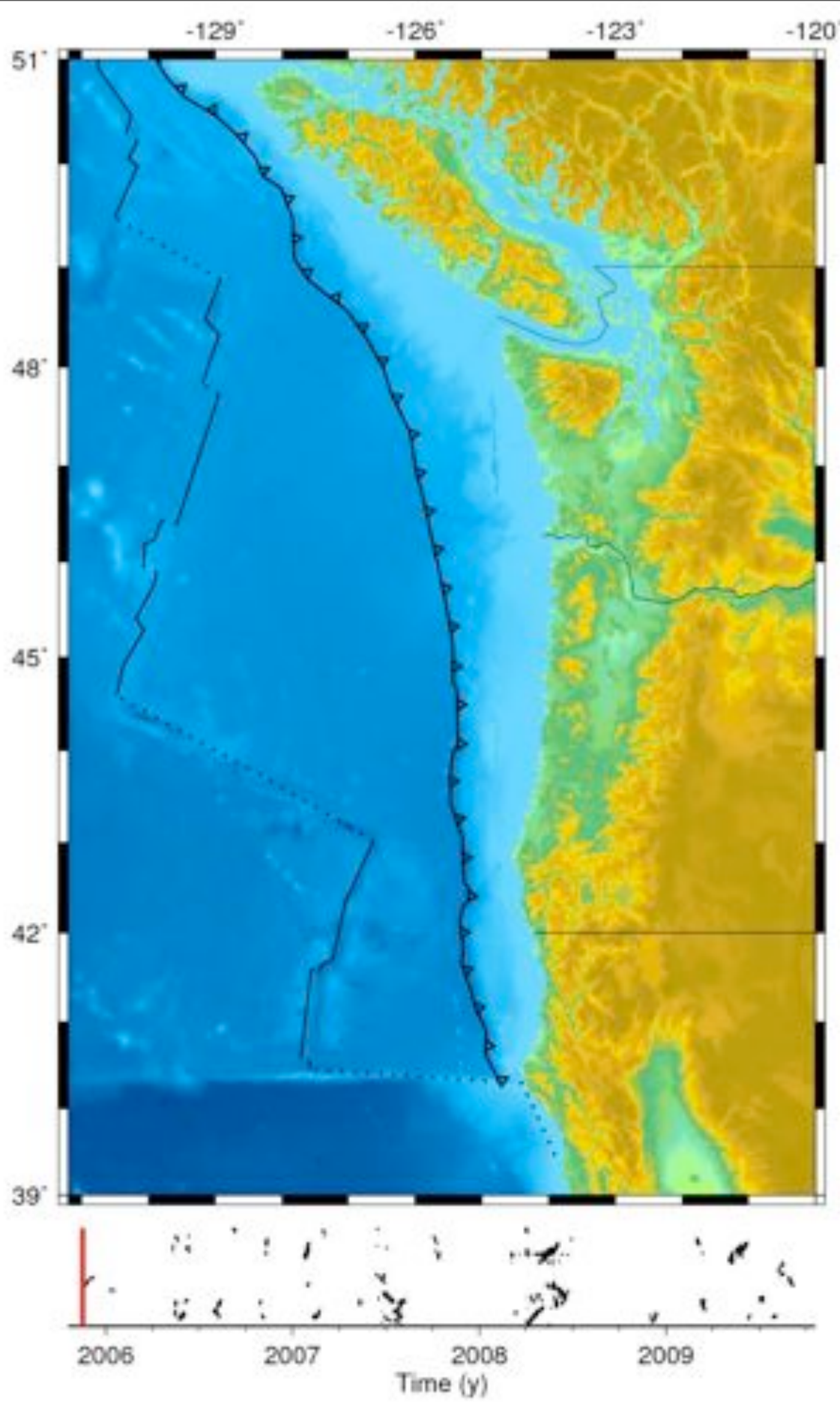


Ide, Nature, 2010

Tremor fills Cascadia

Courtesy Mike Brudzinski

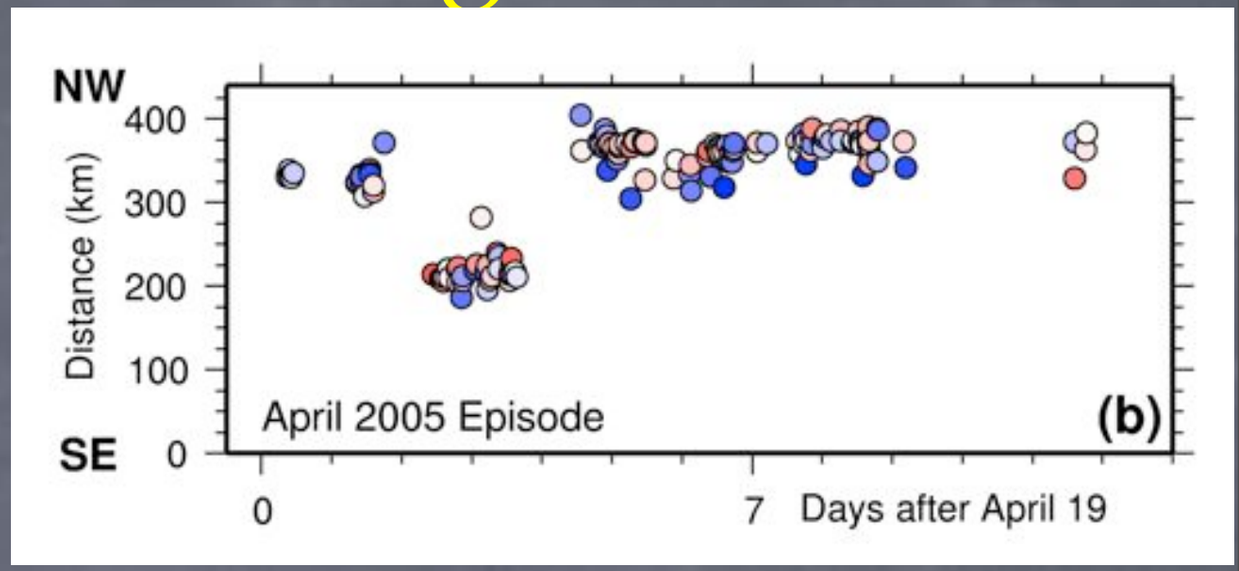
Tremor fills Cascadia



Courtesy Mike Brudzinski

Along Strike Migration and Segmentation

Kao et al., 2007



- Steady movement, halting, jumping
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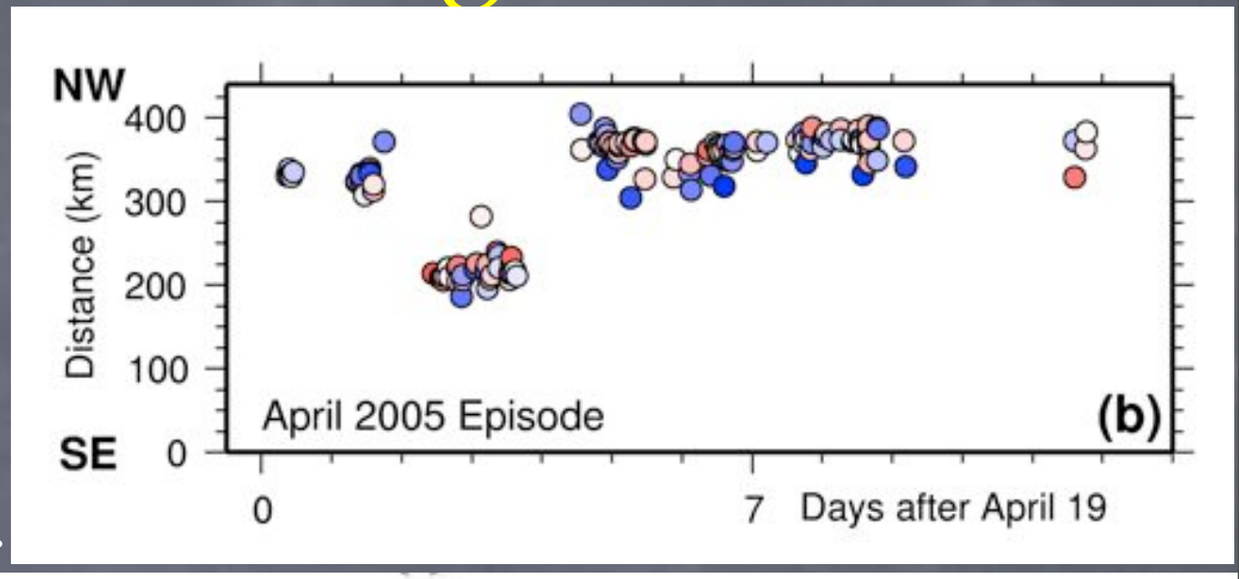
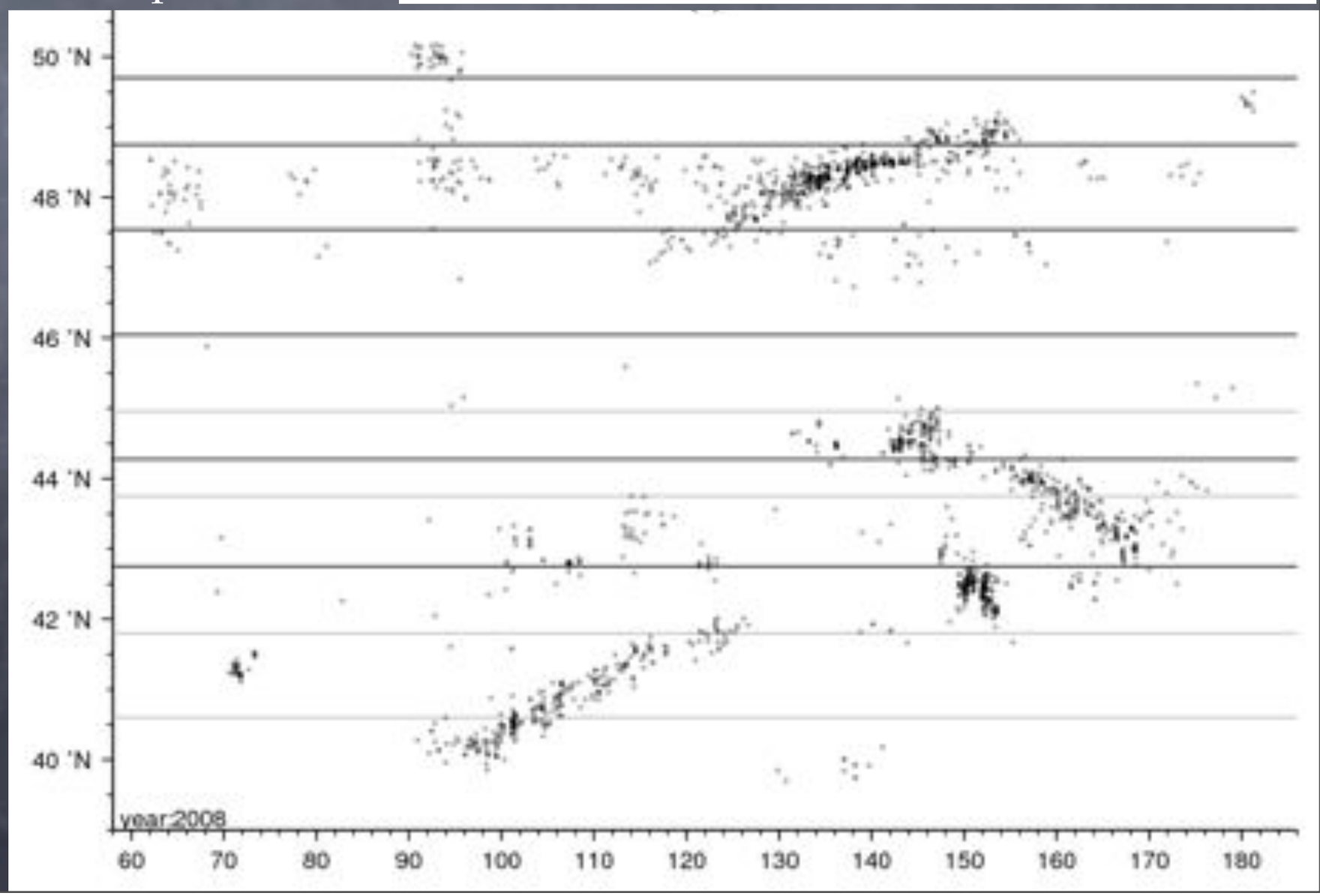
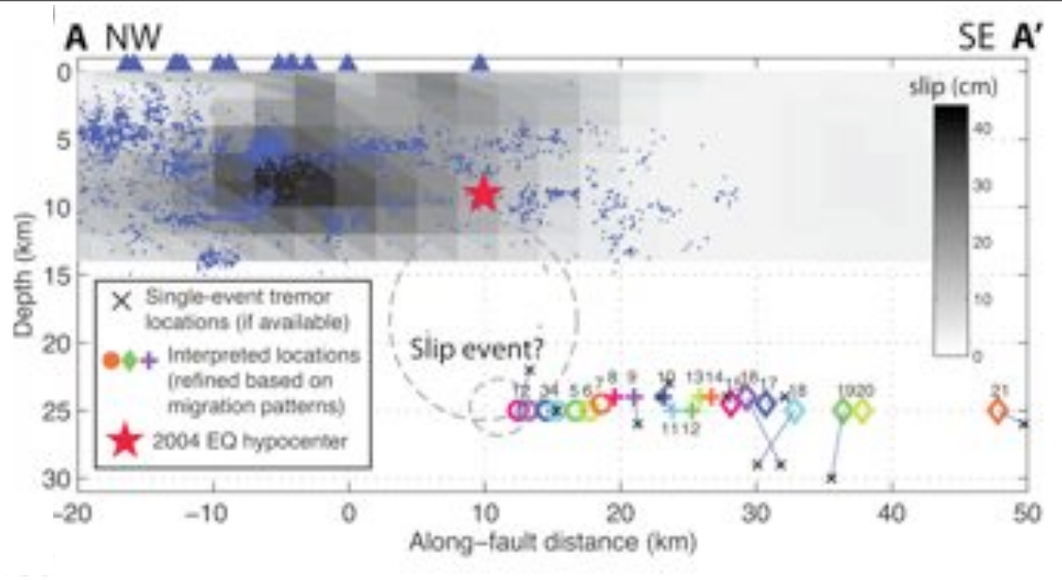
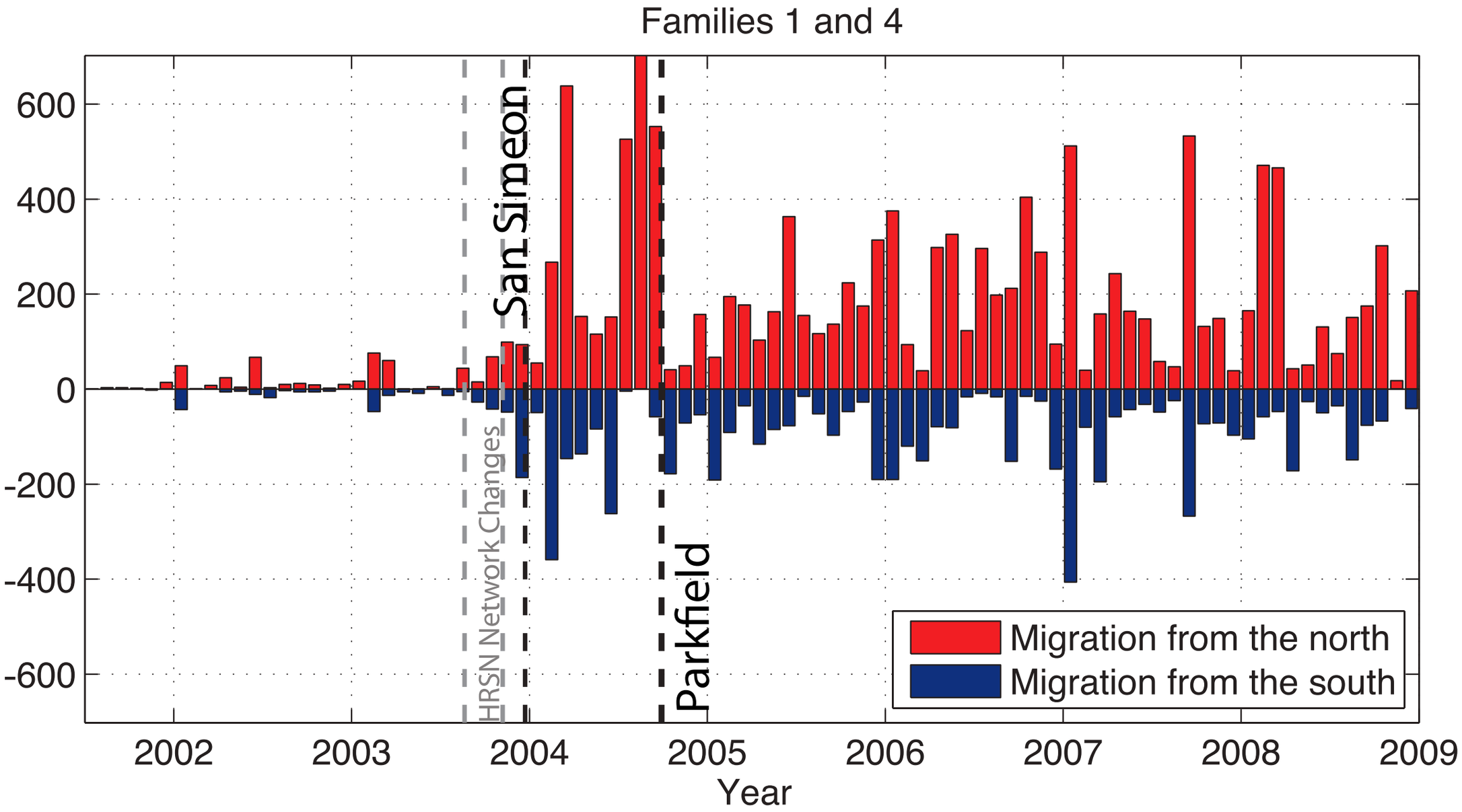


Brudzinski, pers. comm.



Parkfield precursors?

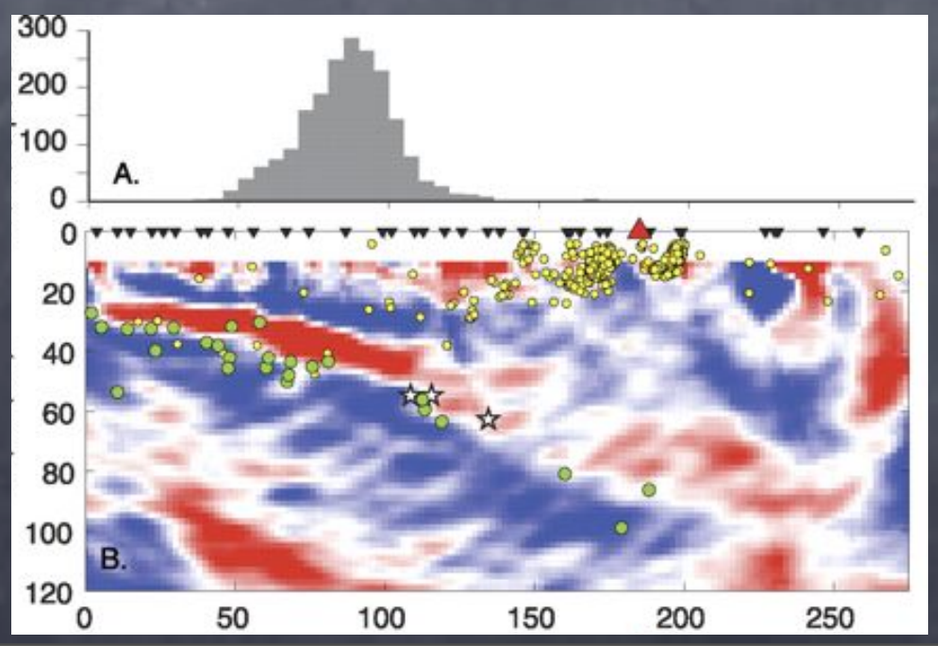




Shelly, GRL, 2009

Several reasons for public to care

- Are locations of intra- and inter-plate quakes illuminated by tremor geometry?
- Crustal earthquakes distribution?
- Does tremor pattern change before megaquakes?



Abers et al., Geology, 2009

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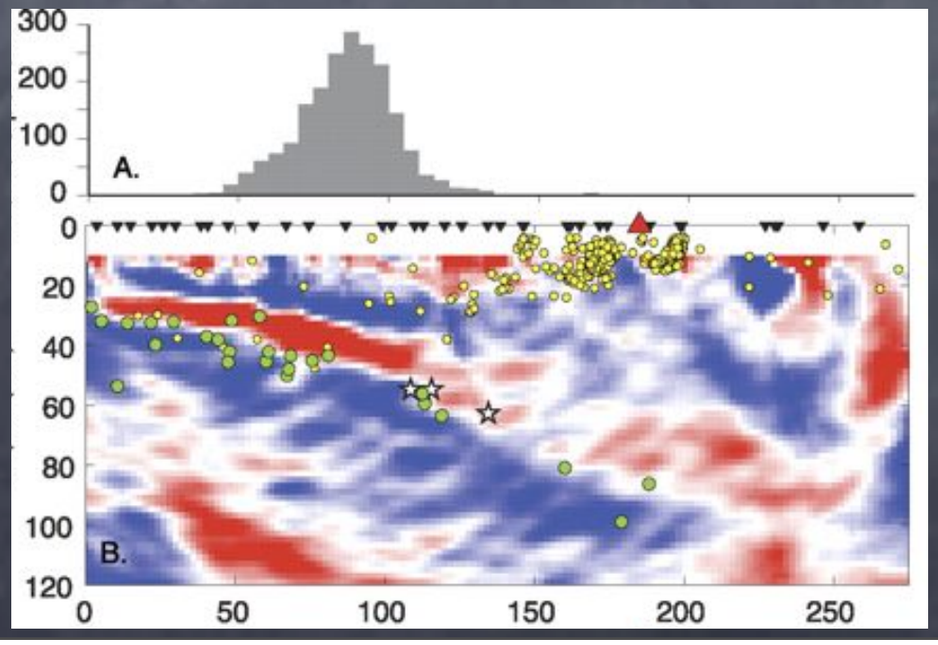
Nov. 17, 2009
in Seattle Times



Abers et al.,
Geology, 2009

Wrap-up

- Activity migration
  - Along strike ~10 km/day,
  - Reversing pulses ~100 km/day
  - Down-dip 10s of km/hr,
  - Flickering by the second,
  - Repeating patches, and
  - Perhaps jumping 100s of kms.
- Progress will come from further observations
  - ETS relation to earthquakes,
  - ETS relation to geology, and
  - ETS fine-scale spatiotemporal evolution.
- Imagination fails me here.