Seismic and Aseismic Processes from the Modern Record

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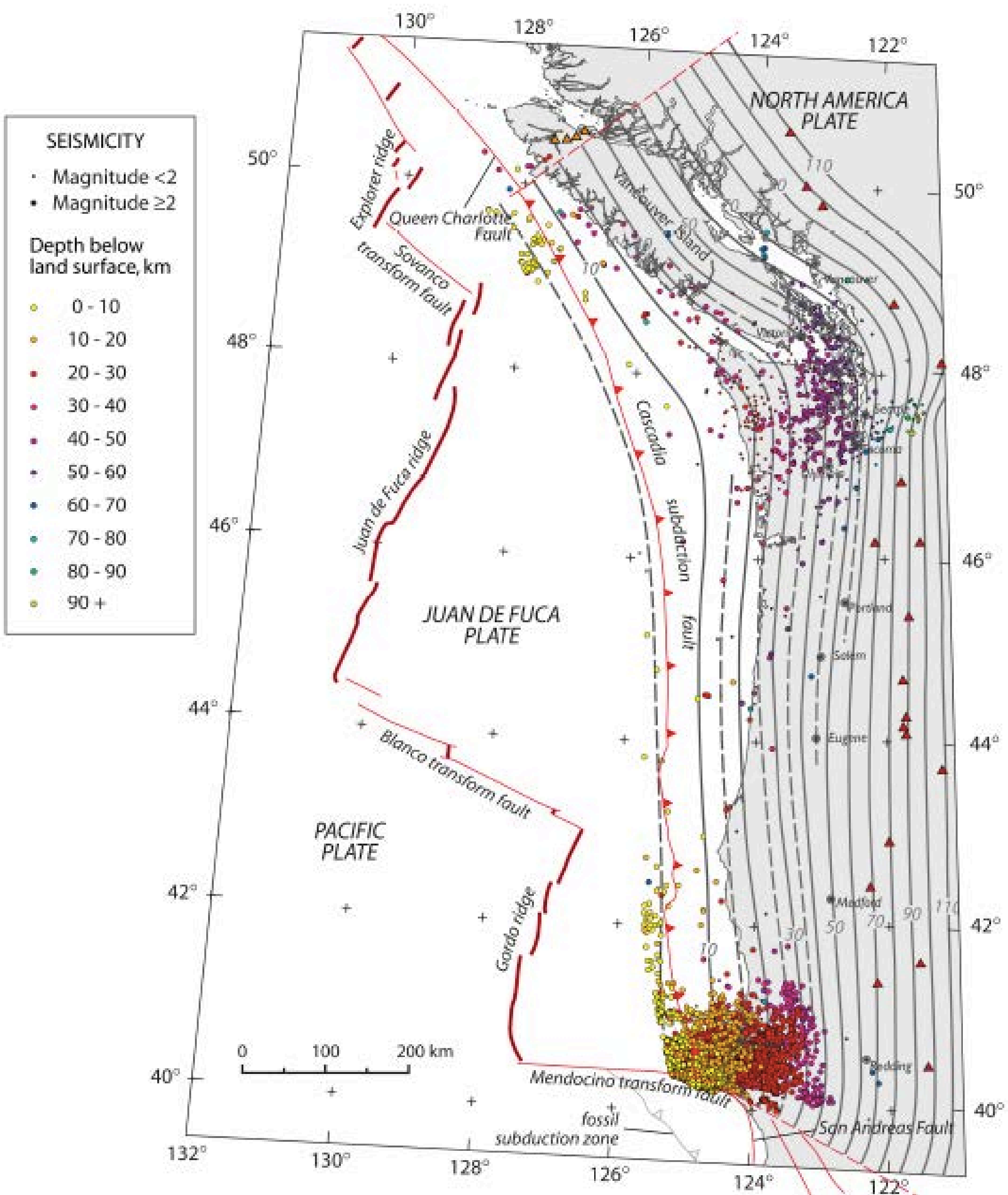
GeoPRISMS- EarthScope Science Workshop for Cascadia

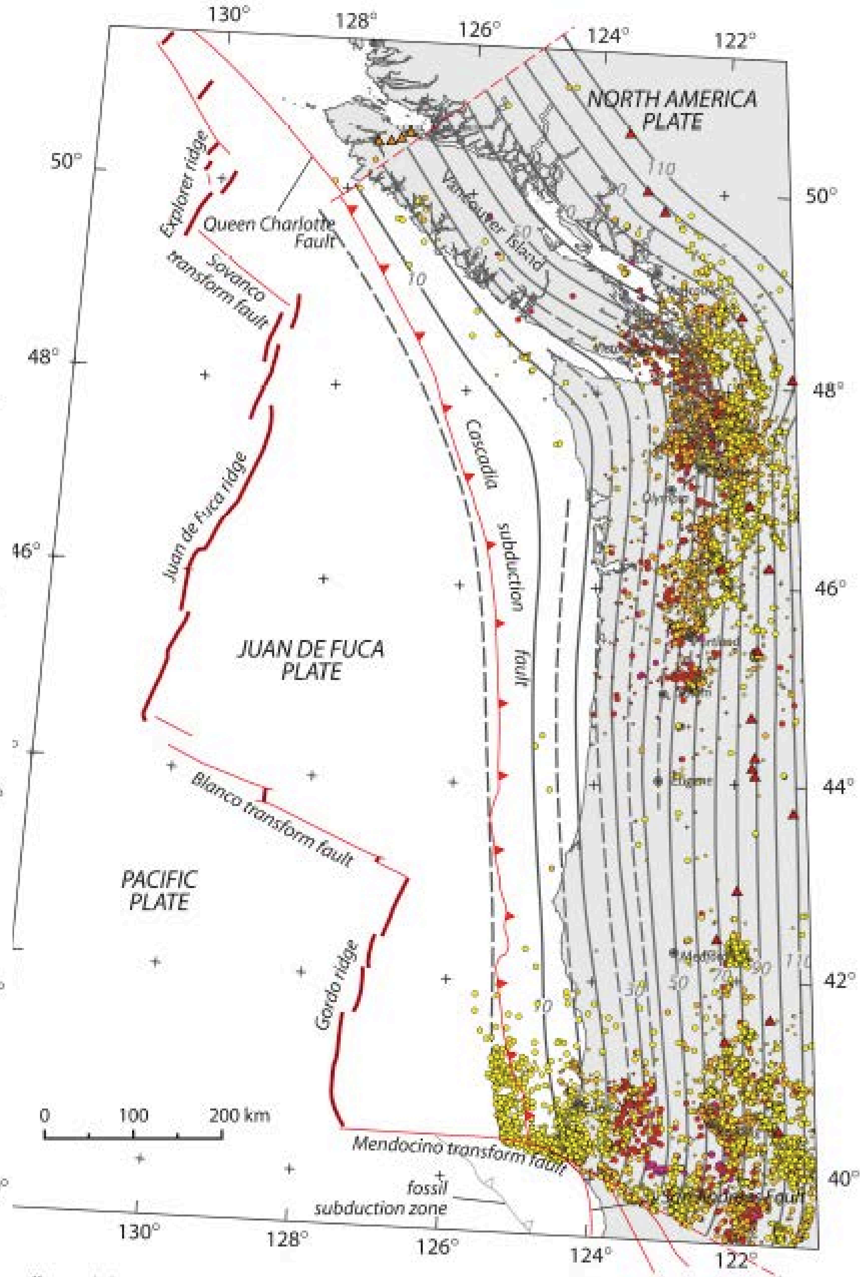
April 5, 2012

McCrory 2006 seismicity

Intraslab

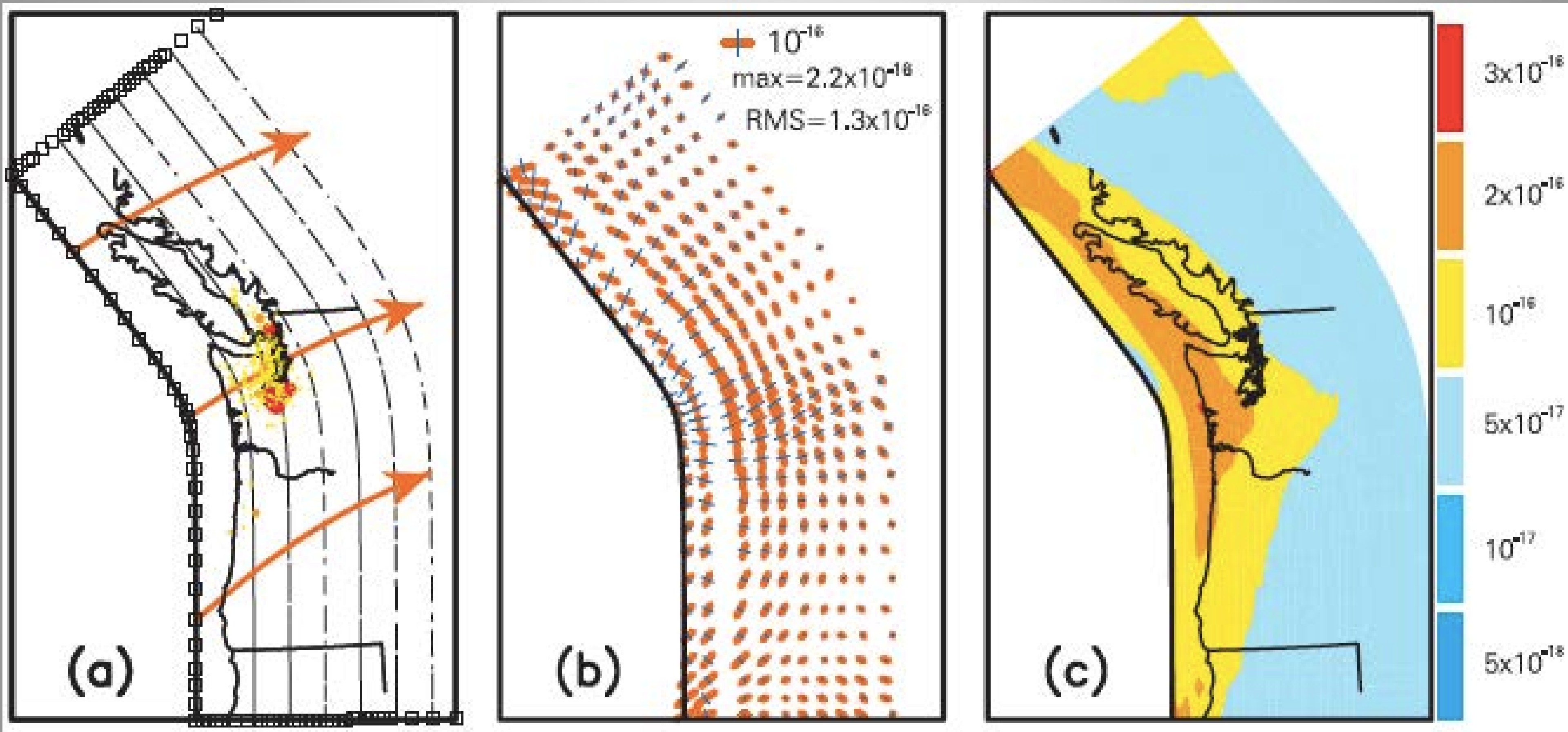


North American Plate



Membrane strain rate for fixed slab geometry

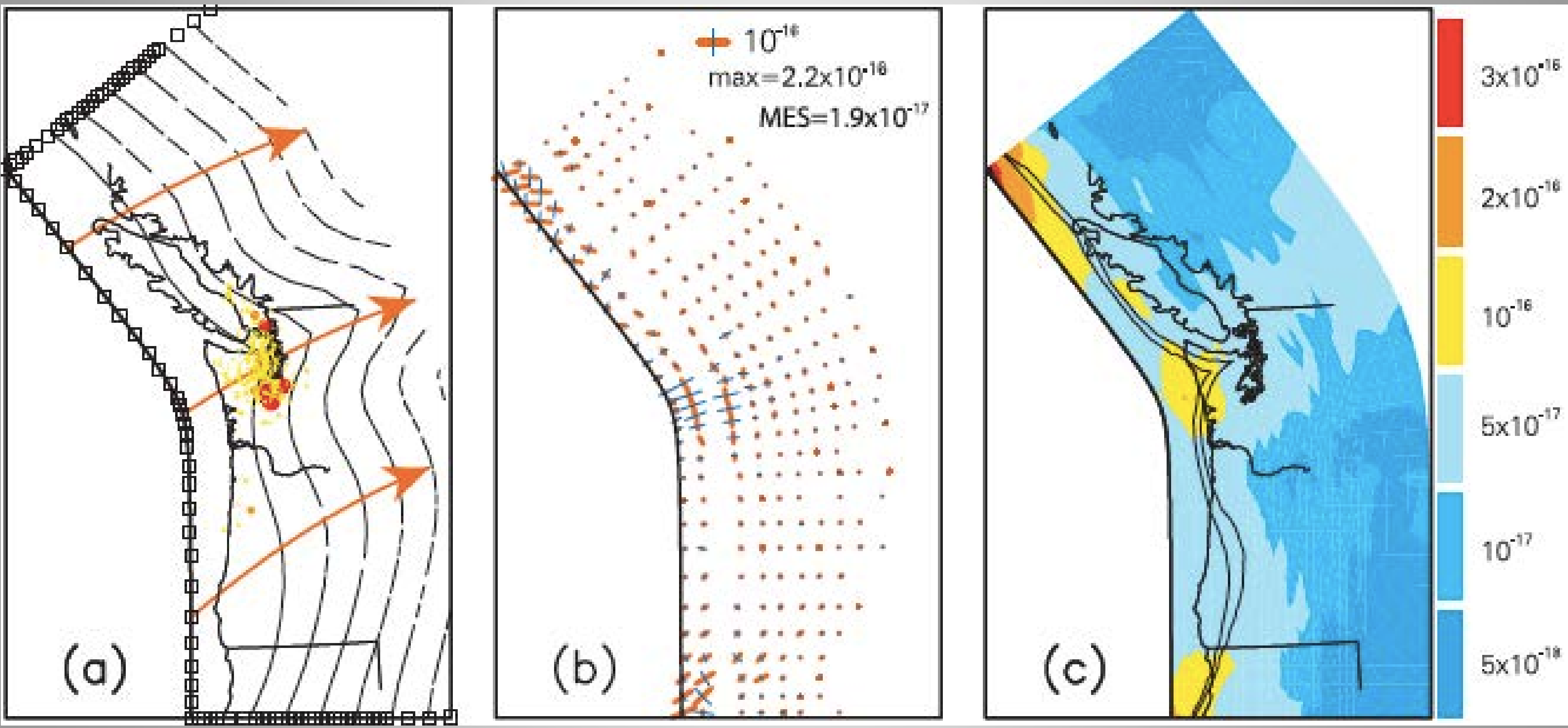
Mean: $1.3 \cdot 10^{-16}\ s^{-1}$



Chiao and Creager, 2002

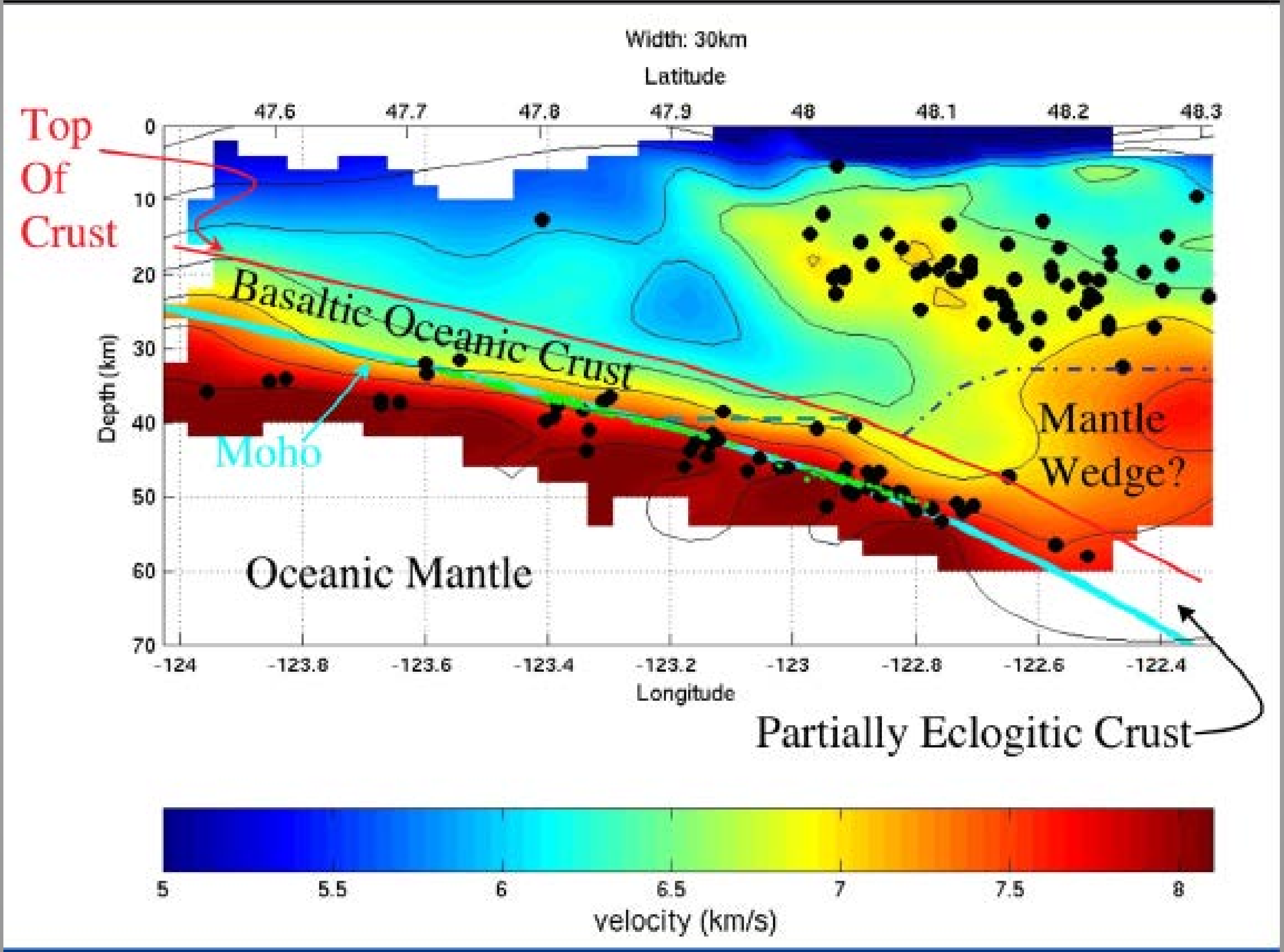
Membrane strain rate for valiable slab geometry

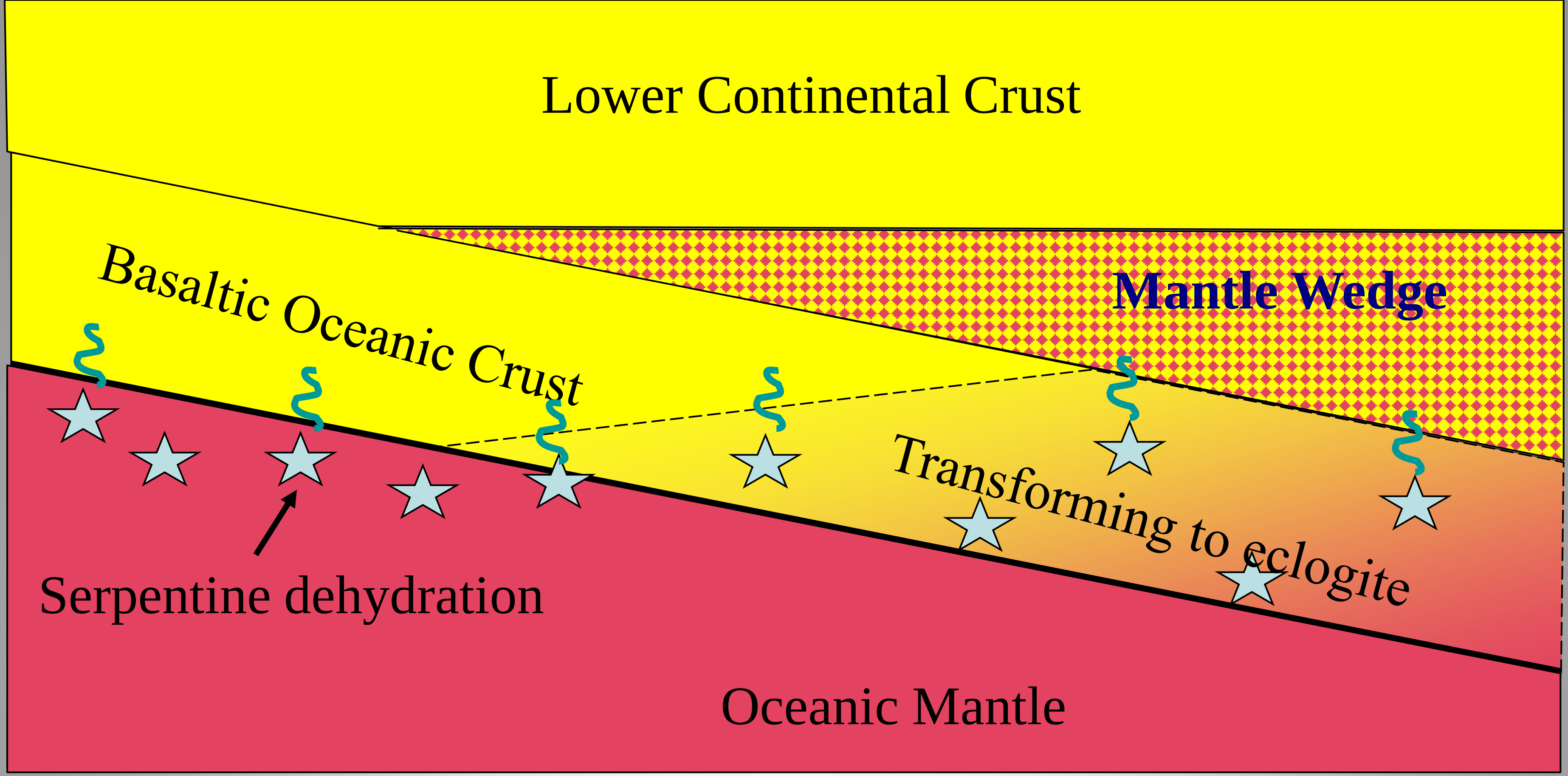
Mean: $1.9*10^{-17}\ s^{-1}$



Chiao and Creager, 2002

(Preston et al. 2003)

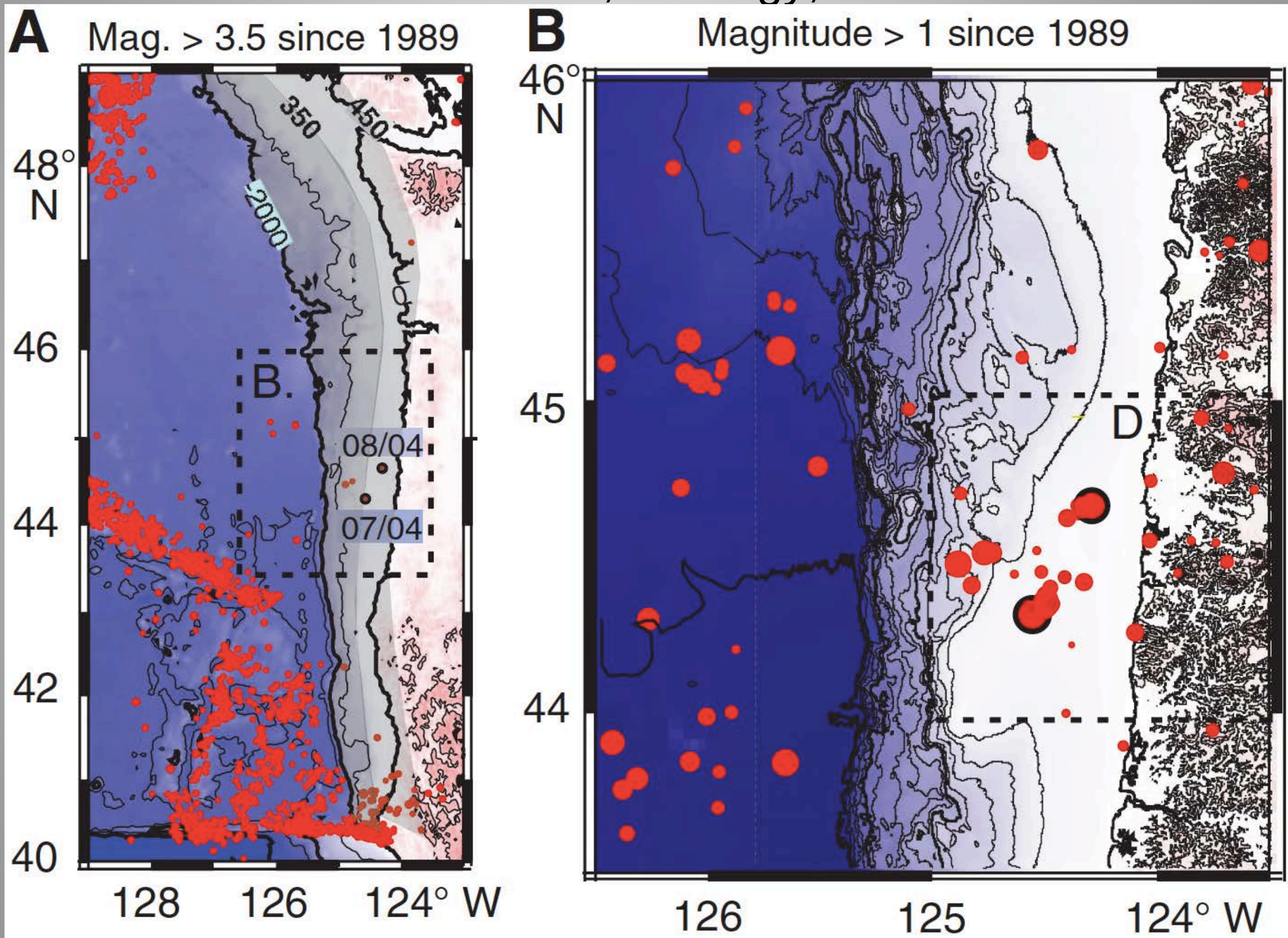




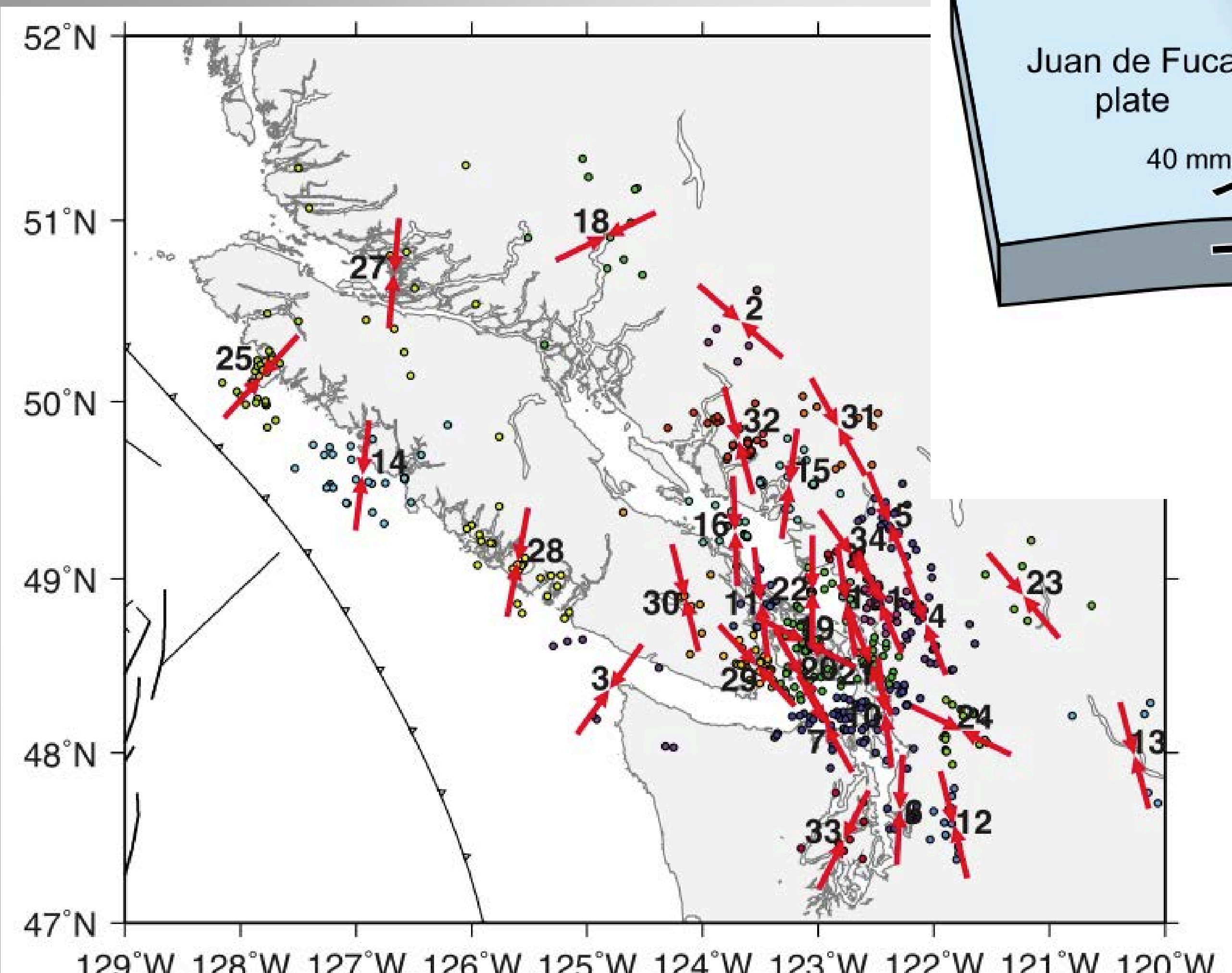
- Before the slab Moho reaches a depth of 45 km most intraslab earthquakes occur within the subducting mantle, consistent with temperature induced serpentinite dehydration.
- East of this contour most intraslab earthquakes occur within the subducting crust, consistent with pressure induced basalt-to-eclogite dehydration reactions. (Preston et al., 2003)

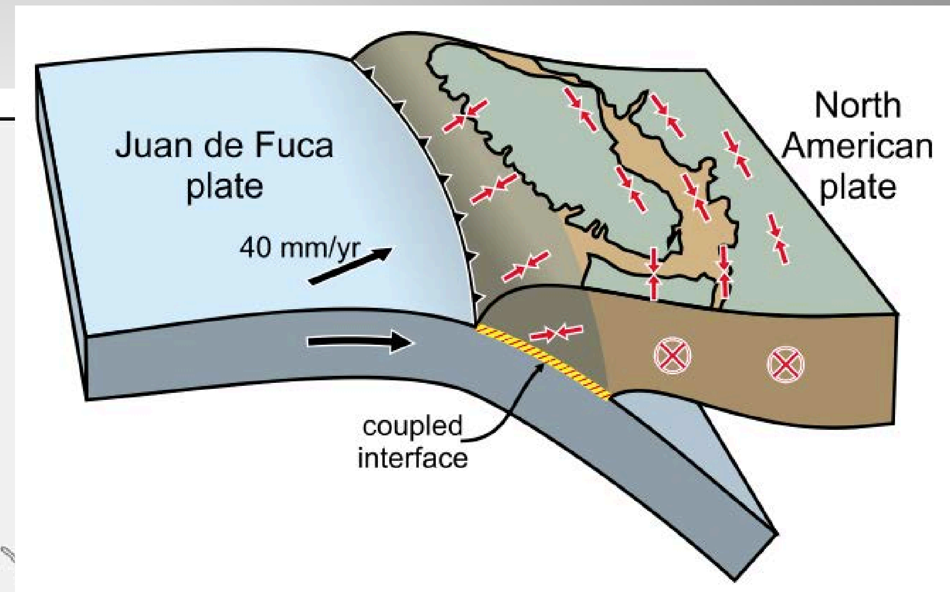
Very few earthquakes on plate interface with thrust mechanisms

Trehu et al, Geology, 2008



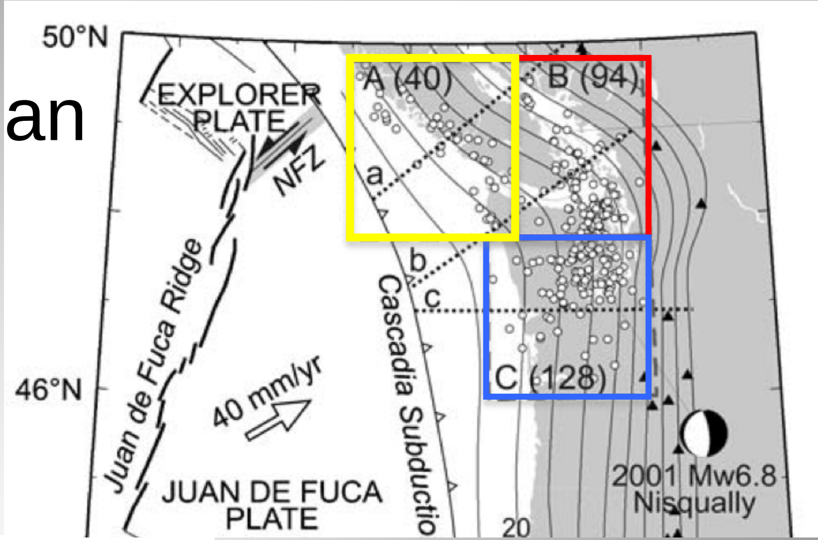
Maximum horizontal stress direction in North American plate

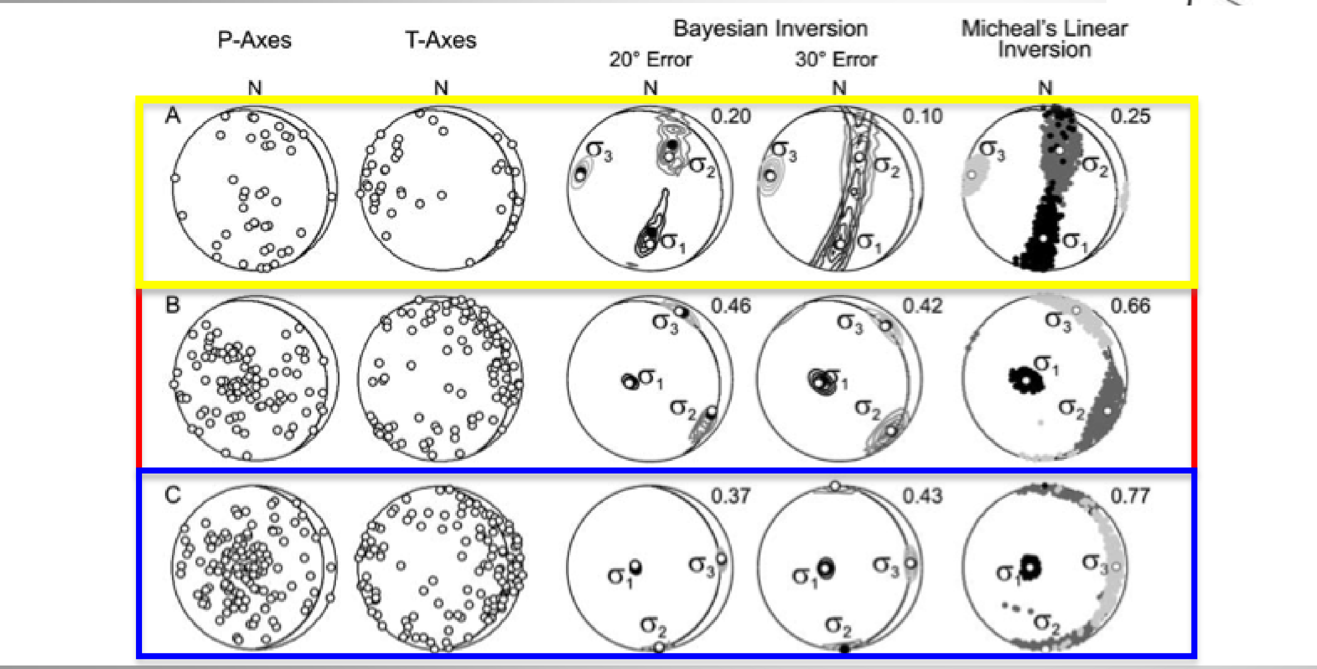




Balfour et al 2011

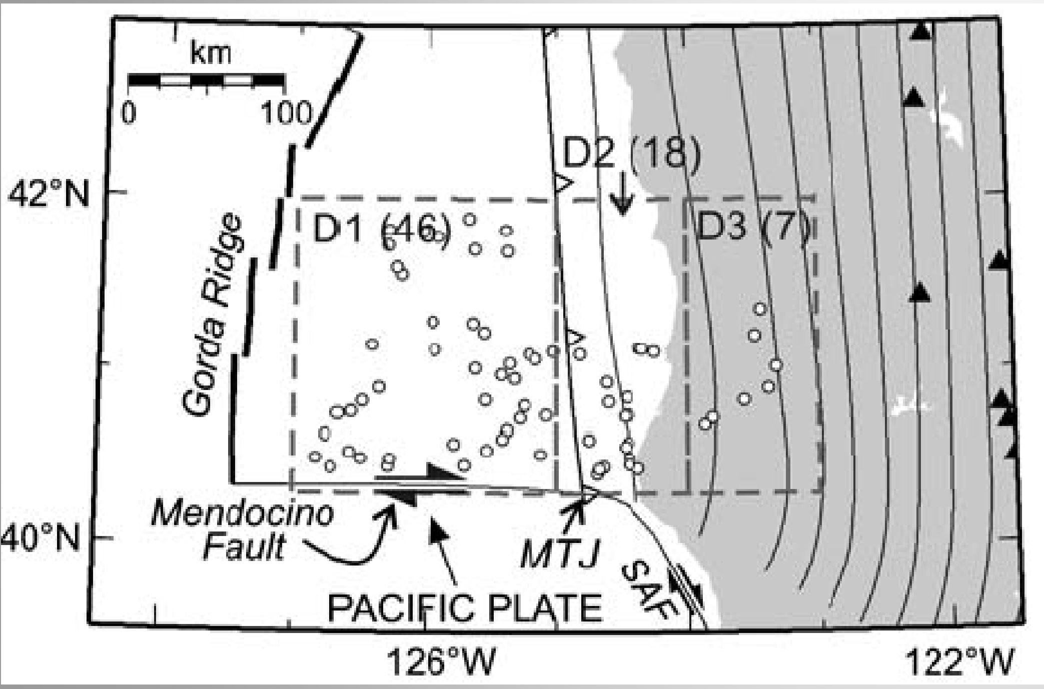
Principal stress directions in Juan De Fuca plate:
Down-dip extension
Slab-normal compression

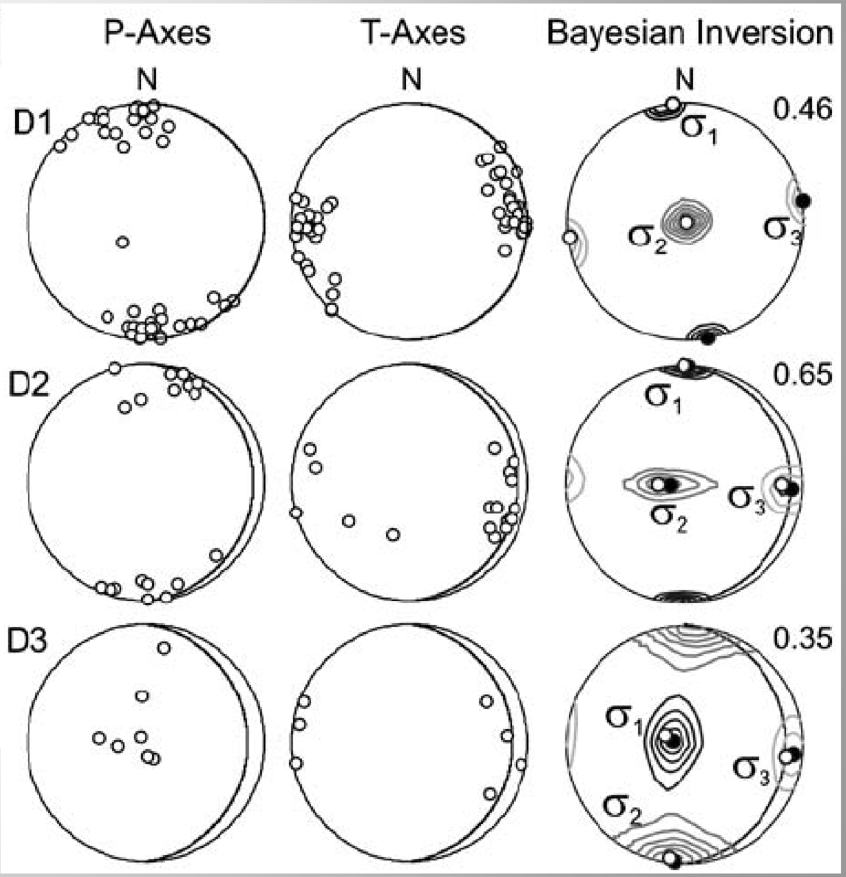


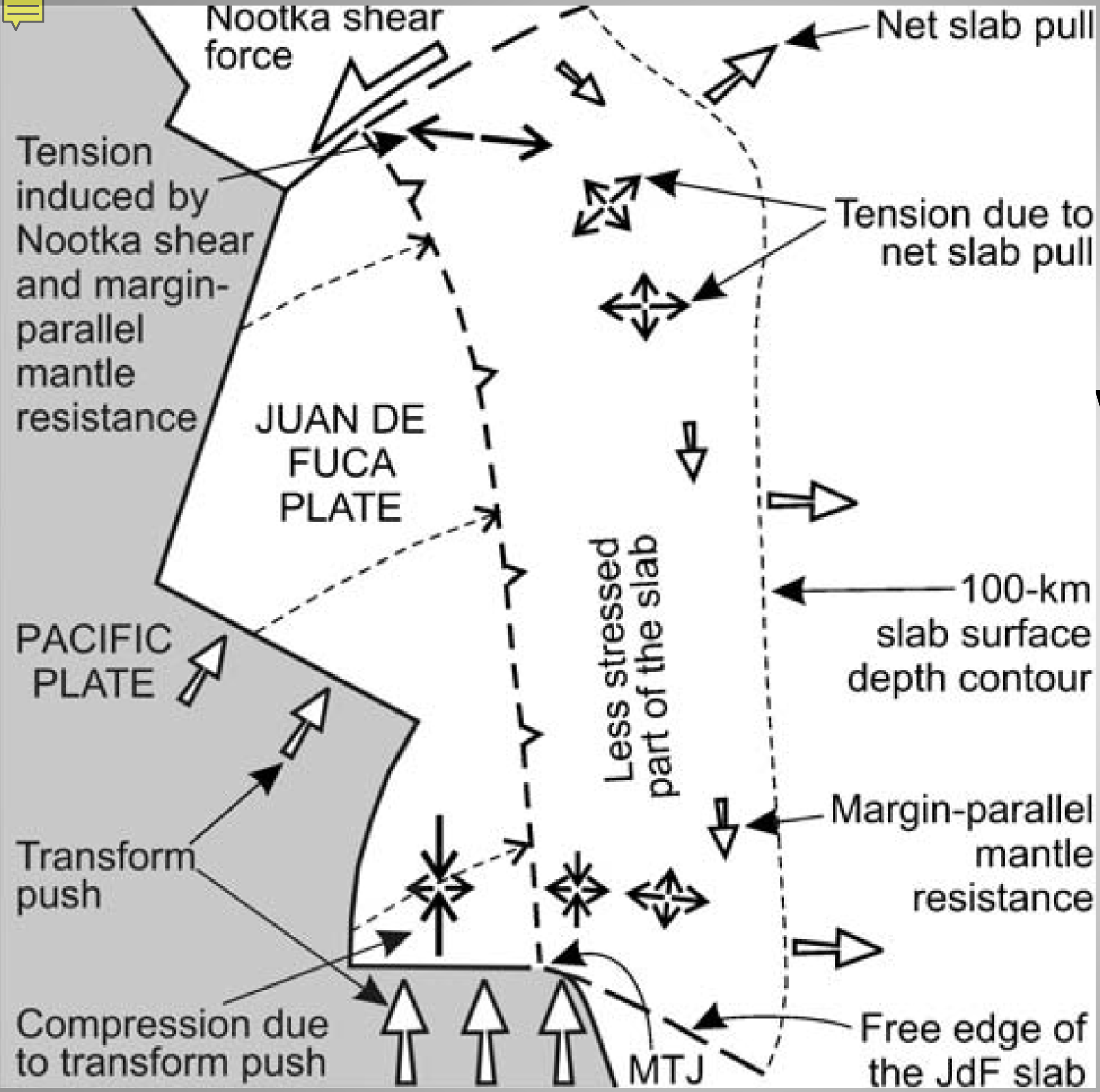


Wada et al 2010

Gorda Plate:
prior to subduction: N-S compression
subducting plate: down-dip extension





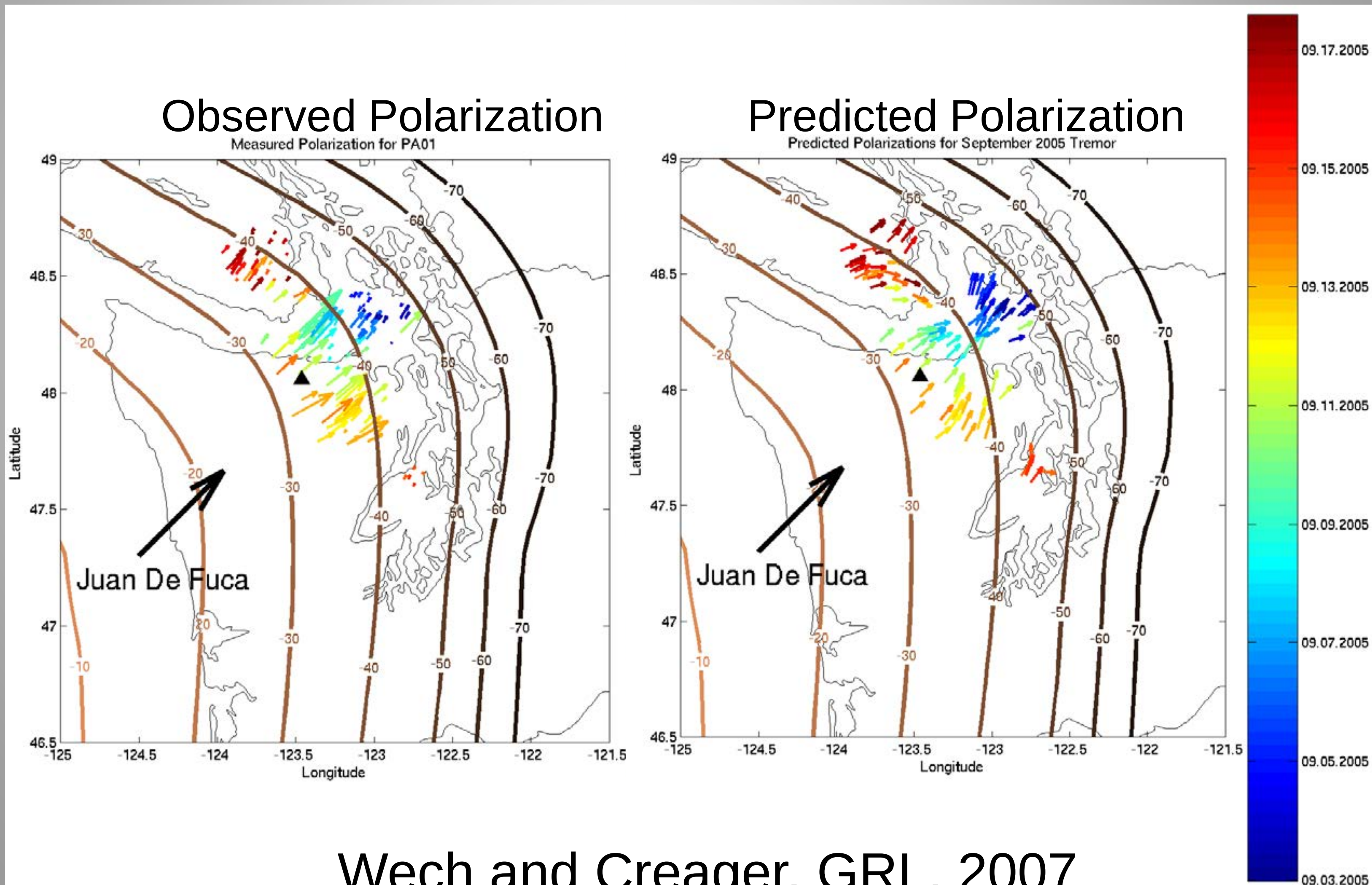


Wada et al., 2010

Cascadia Seismicity

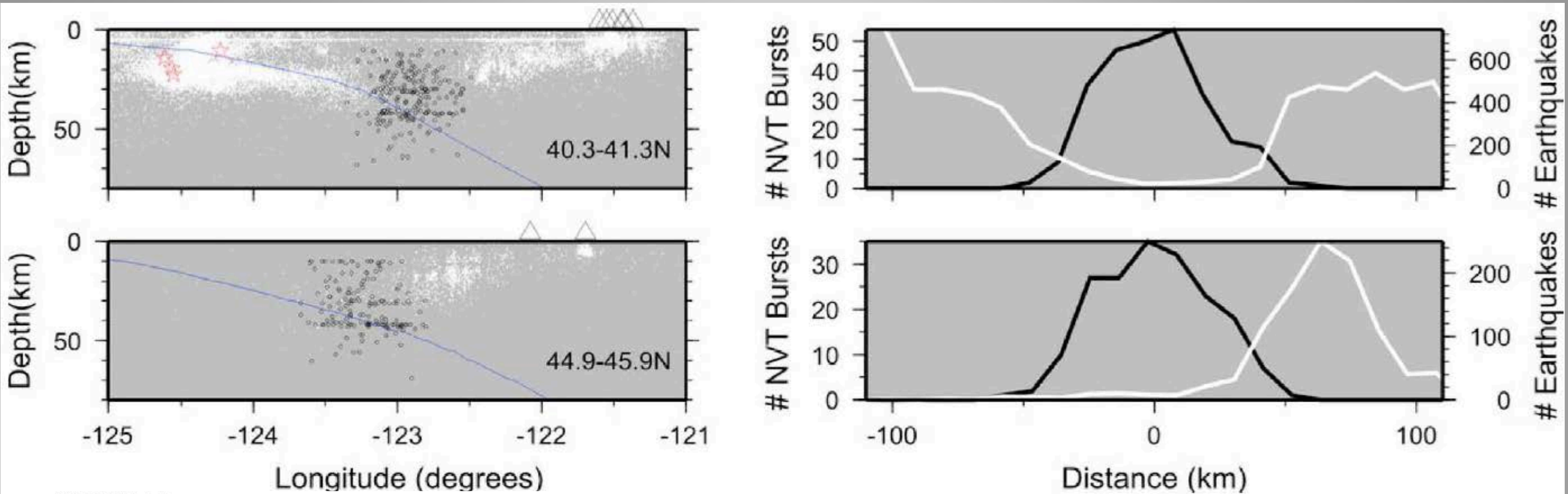
- Plate interface earthquakes
  - Very few earthquakes with thrust mechanisms, though some in Oregon
  - Continuum of processes from stabling at depth to small slow slip events to large slow slip to megathrust earthquakes
- Intraslab earthquakes:
  - Largest events are 1949, 1965, 2001 in south Puget Sound region
  - Very few events in Oregon because low membrane strain rate?
  - Mechanism are down-dip extension/slab-normal compression
  - Under Vancouver Island see shallow down-dip compressions, from locked zone?
  - Gorda Plate N-S compression from Pacific Plate push
- North American Crust
  - Very active under Puget Sound, quiet throughout most of western Oregon
  - High rate of deformation in Olympic Peninsula, but little seismicity

September 2005 ETS: Observed Tremor Polarization is consistent with Thrust source mechanism

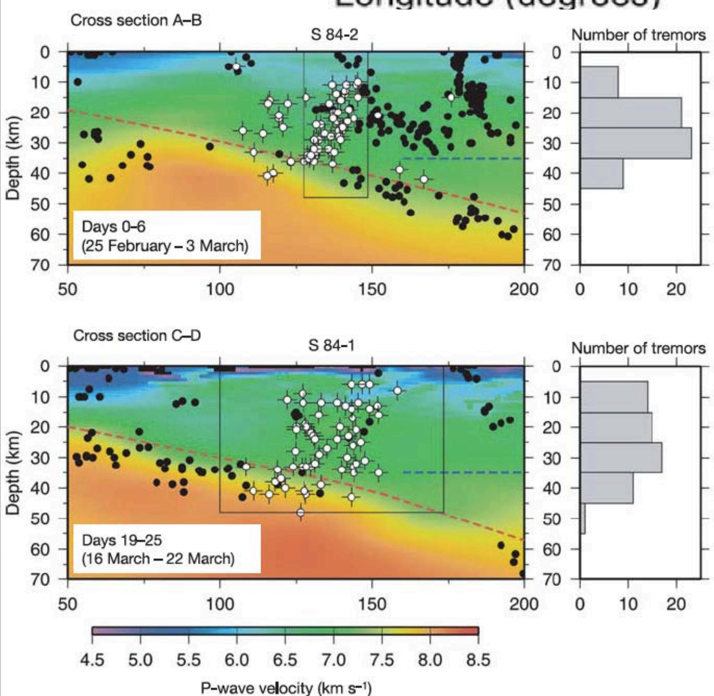


Wech and Creager, GRL, 2007

Tremor avoids earthquakes or visa versa



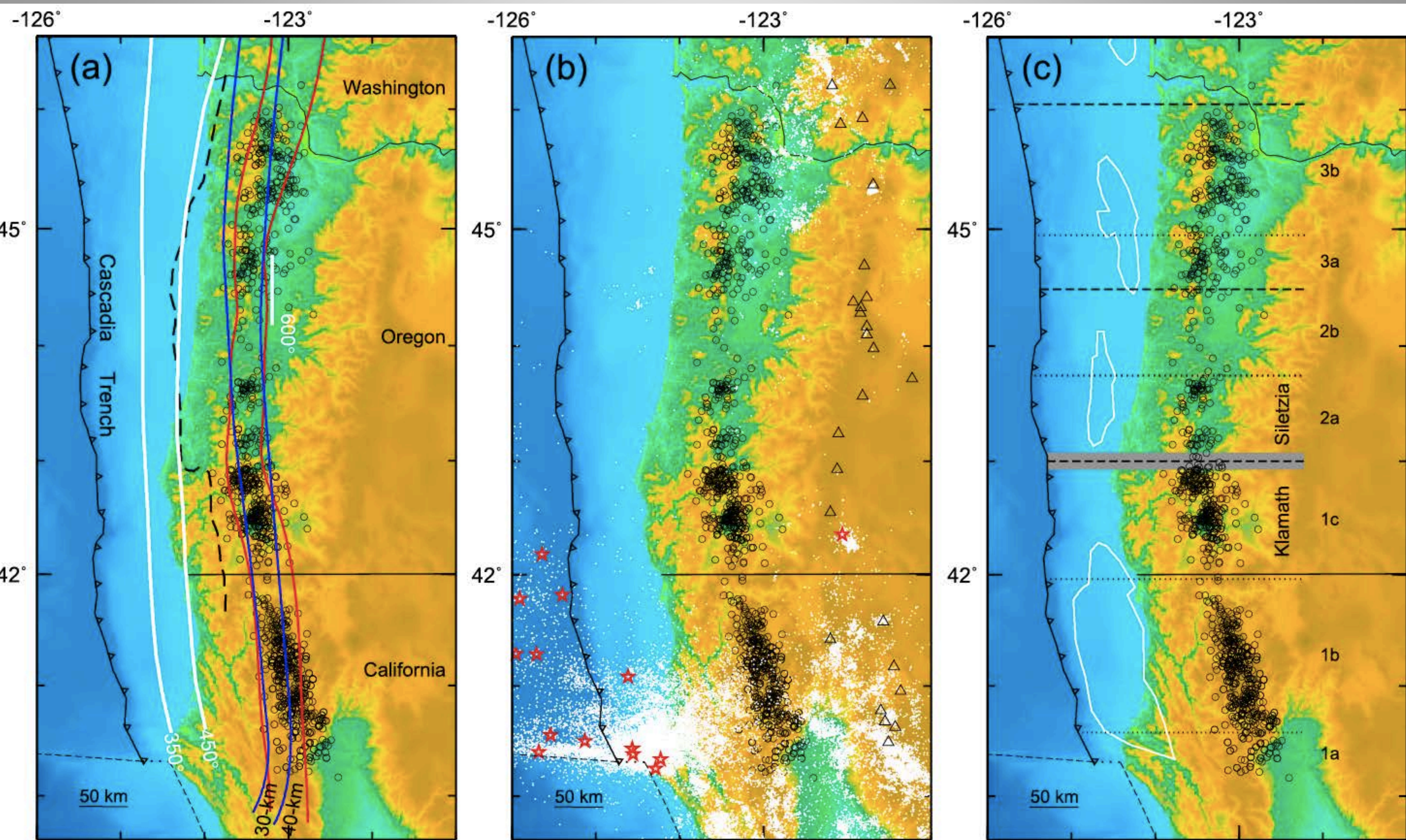
Boyarko and Brudzinski, 2010



Kao et al, 2007

- Earthquakes (white) avoid tremors (black)
- Offshore sedimentary basins correlate with tremor segmentation

Boyarko and Brudzinski, 2010



Transition zone?

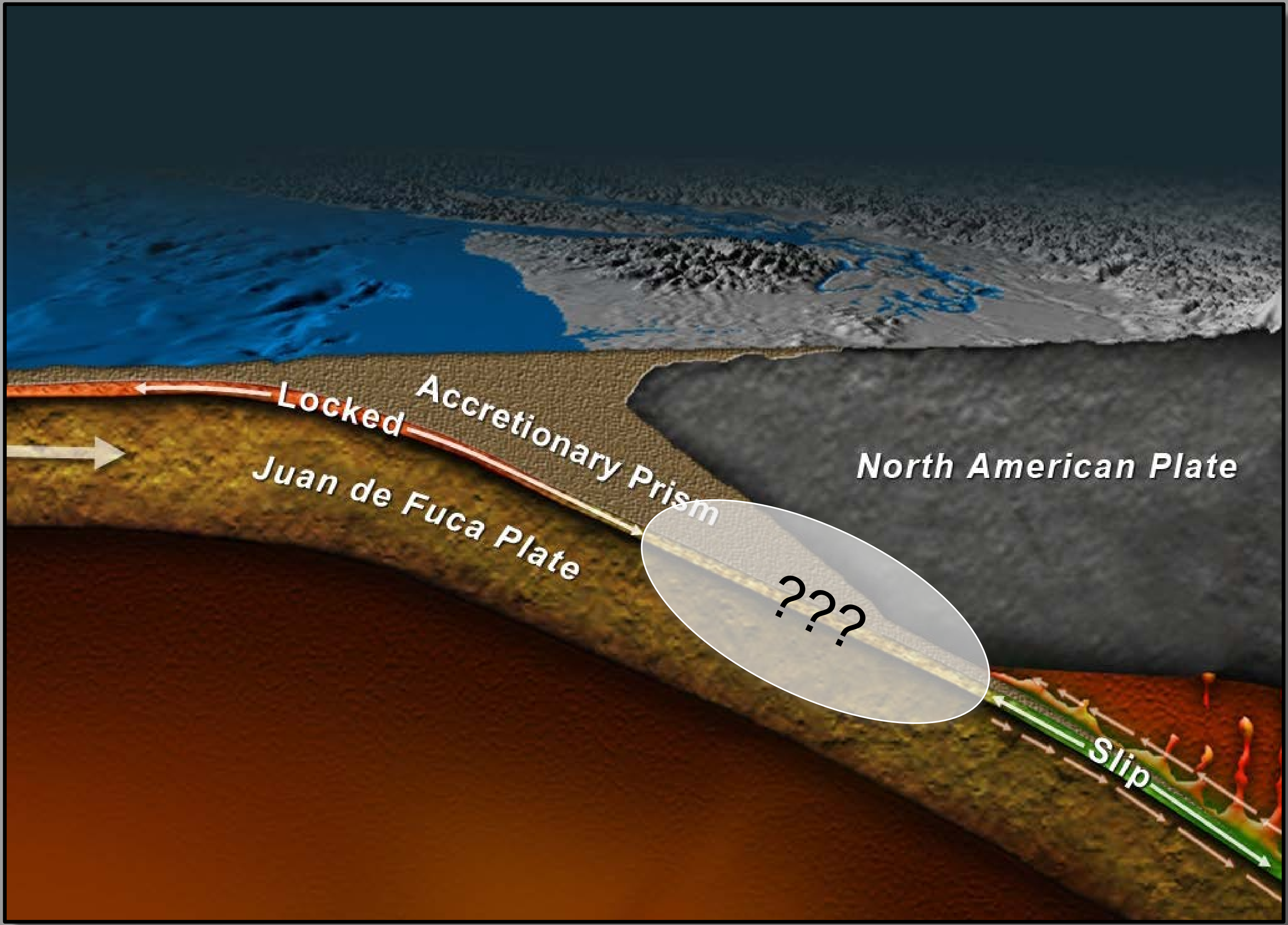
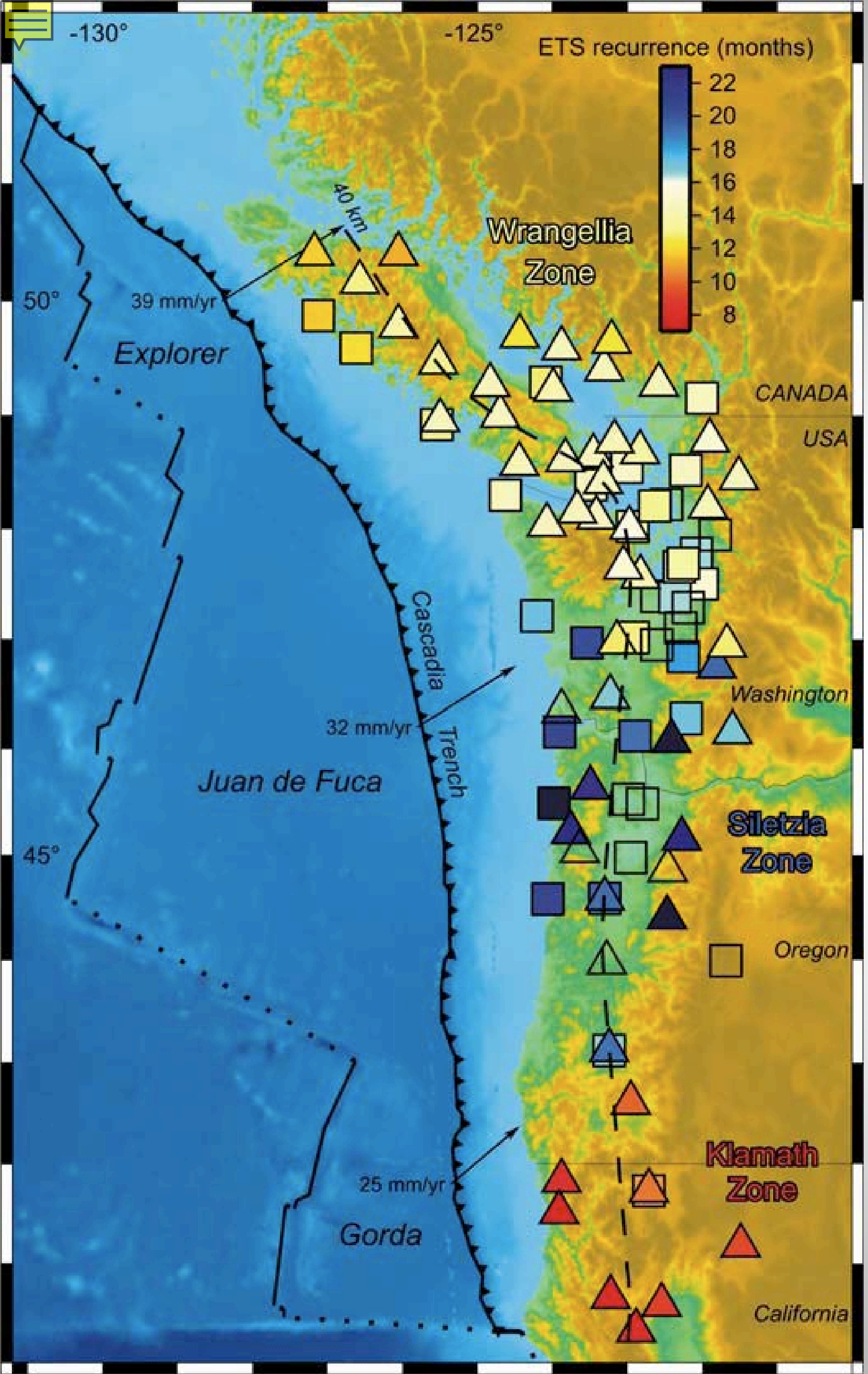
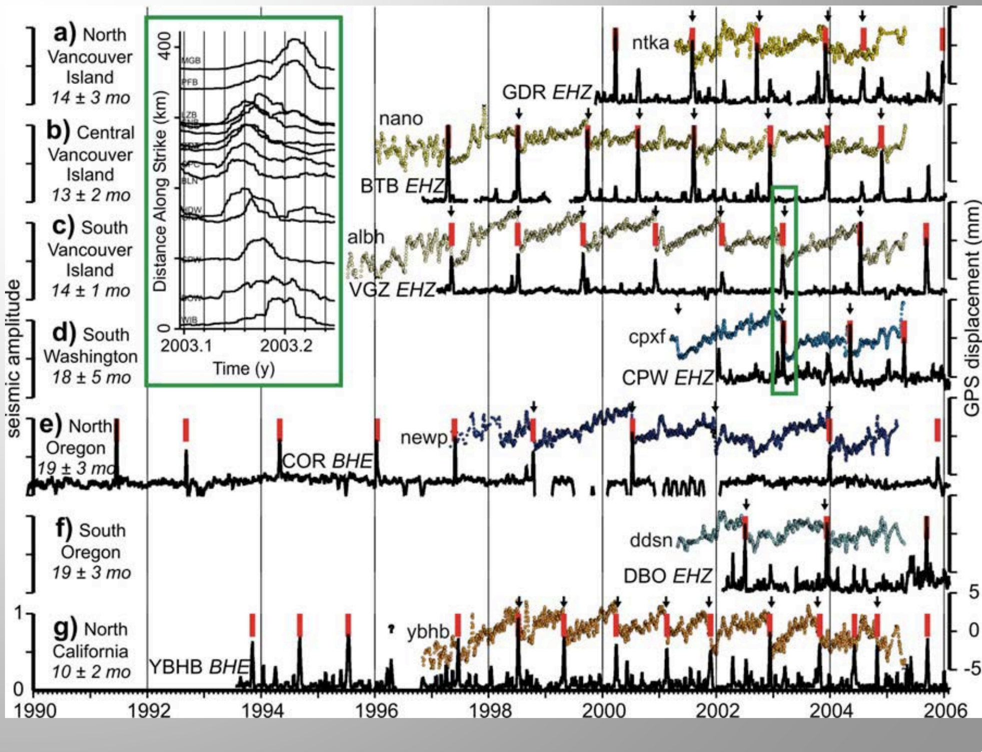
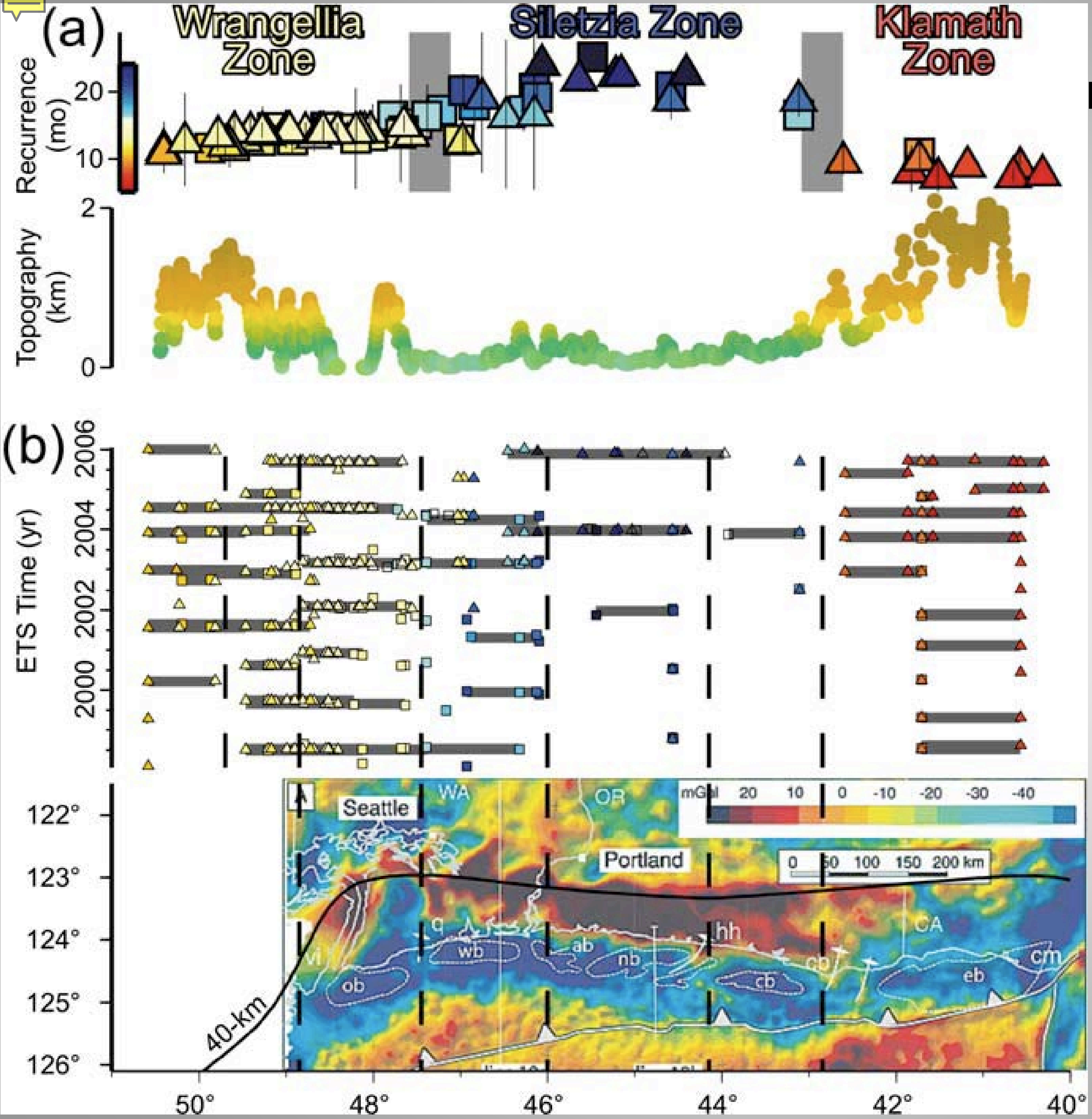


Image from Steve Malone



Brudzinski and Allen, 2007



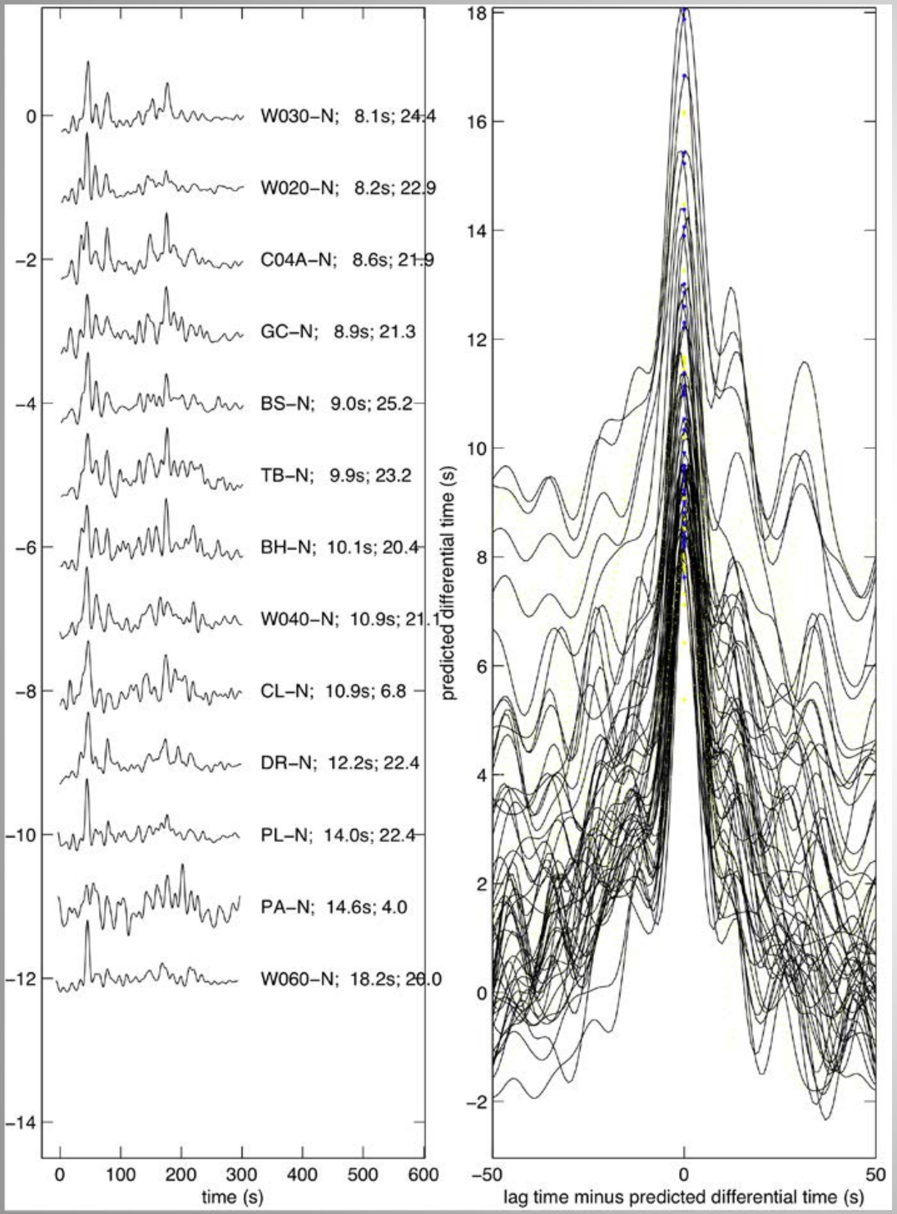


Brudzinski and Allen, 2007

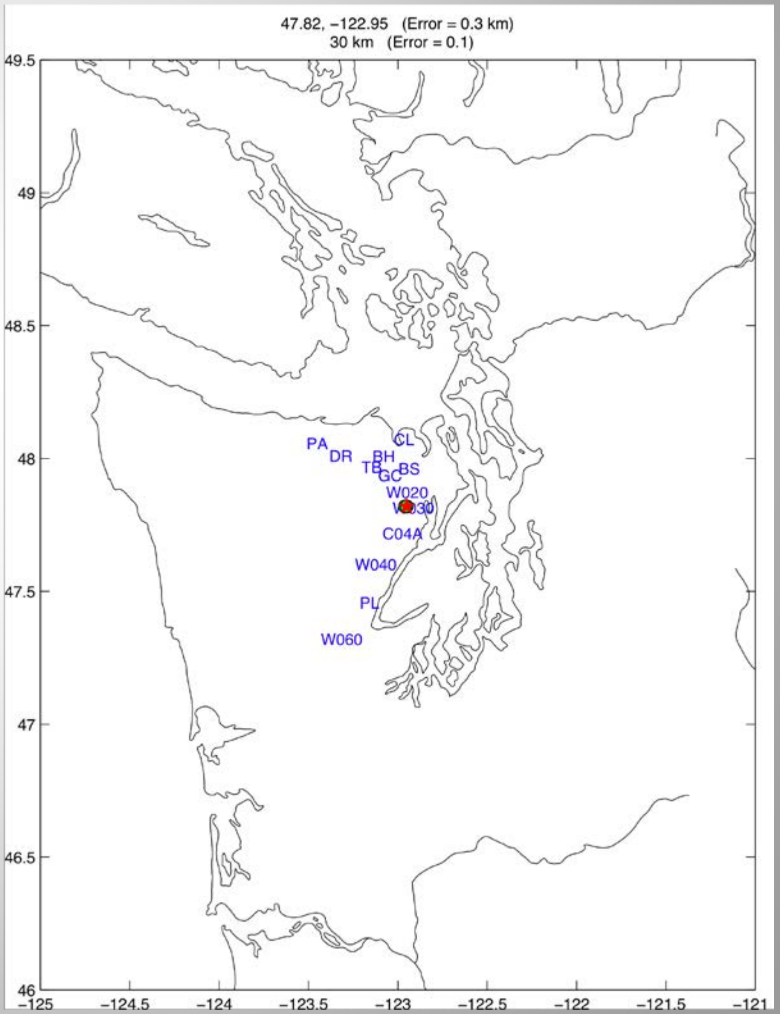
Tremor Location Method

5-minute Envelopes
Aligned for best location

Cross correlation of
envelope pairs

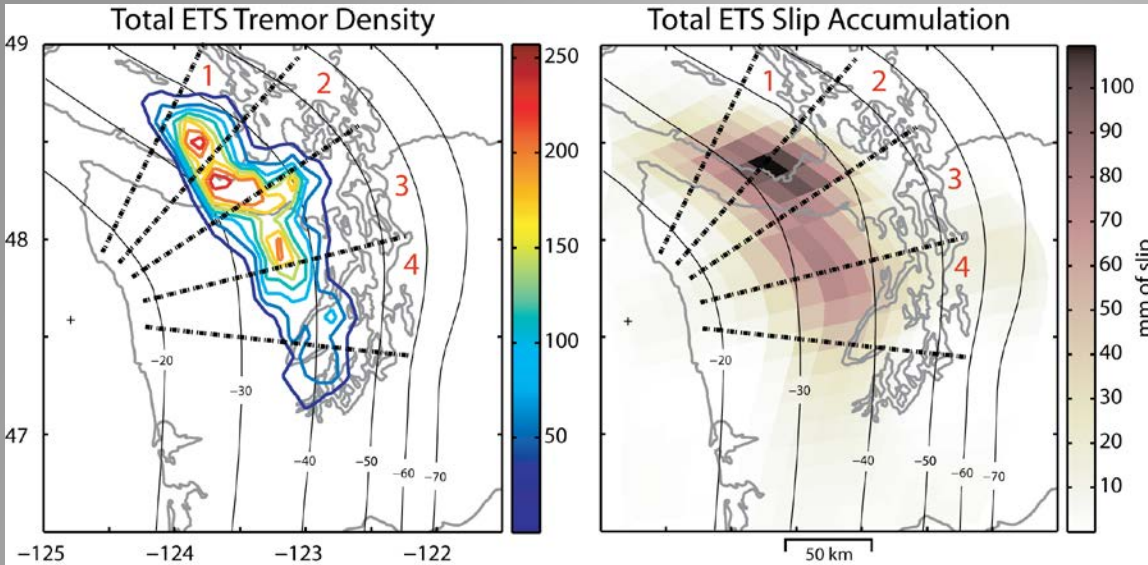


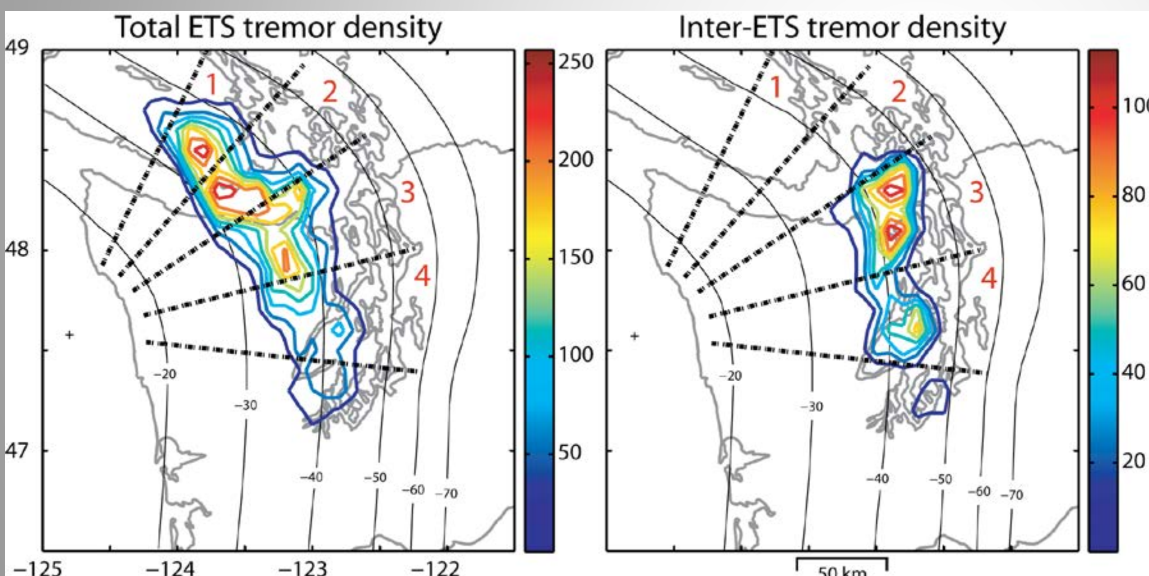
Location of stations and
Tremor epicenter

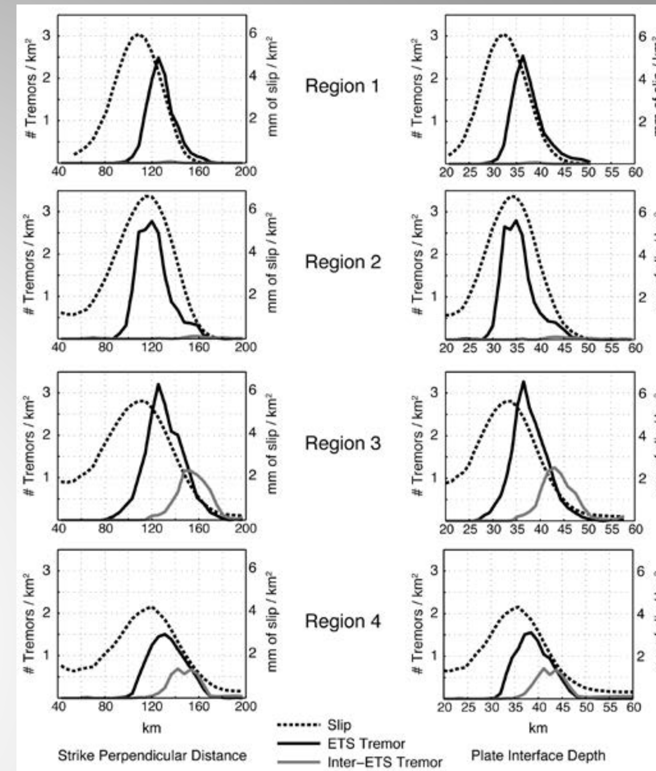


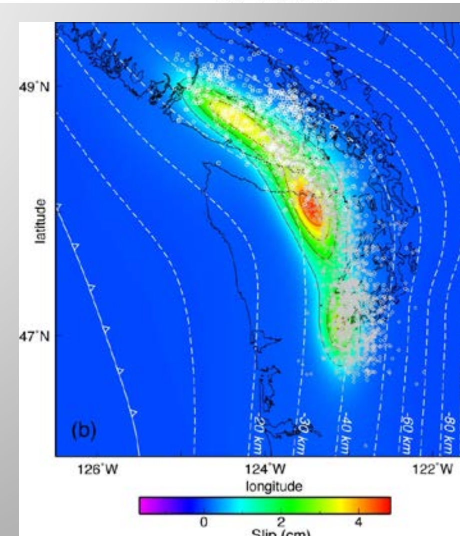
Cascadia Tremor Swarms

- 120,000 5-minute windows of tremor
- Tremor clusters in space and time
- 575 tremor swarms
- Duration range: 1 -> 450 hours
- Large swarms correlate with geodetic slip called Episodic Tremor and Slip
- Tremor duration ~ seismic moment
- $N \sim \tau^{-.66}$
- $N \sim 10^{-bMw}$ Gutenberg Richter relation b=1.0





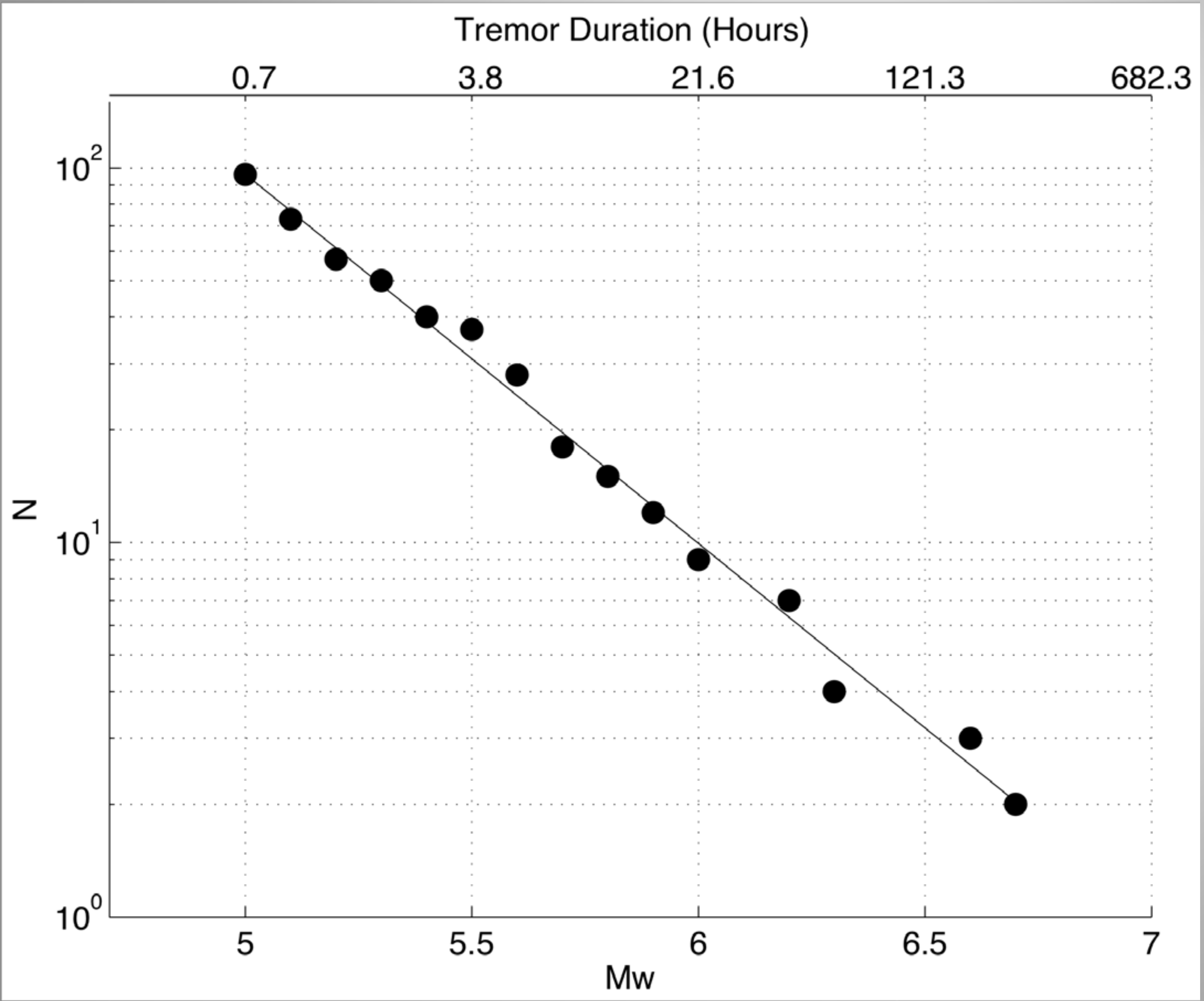




Wech, Creager and Melbourne, JGR, 2009

Gomberg et al., GSA Bull 2010

Gutenberg-Richter Power-Law Distribution of Tremor Swarms



$N = A * \tau^{-0.66}$

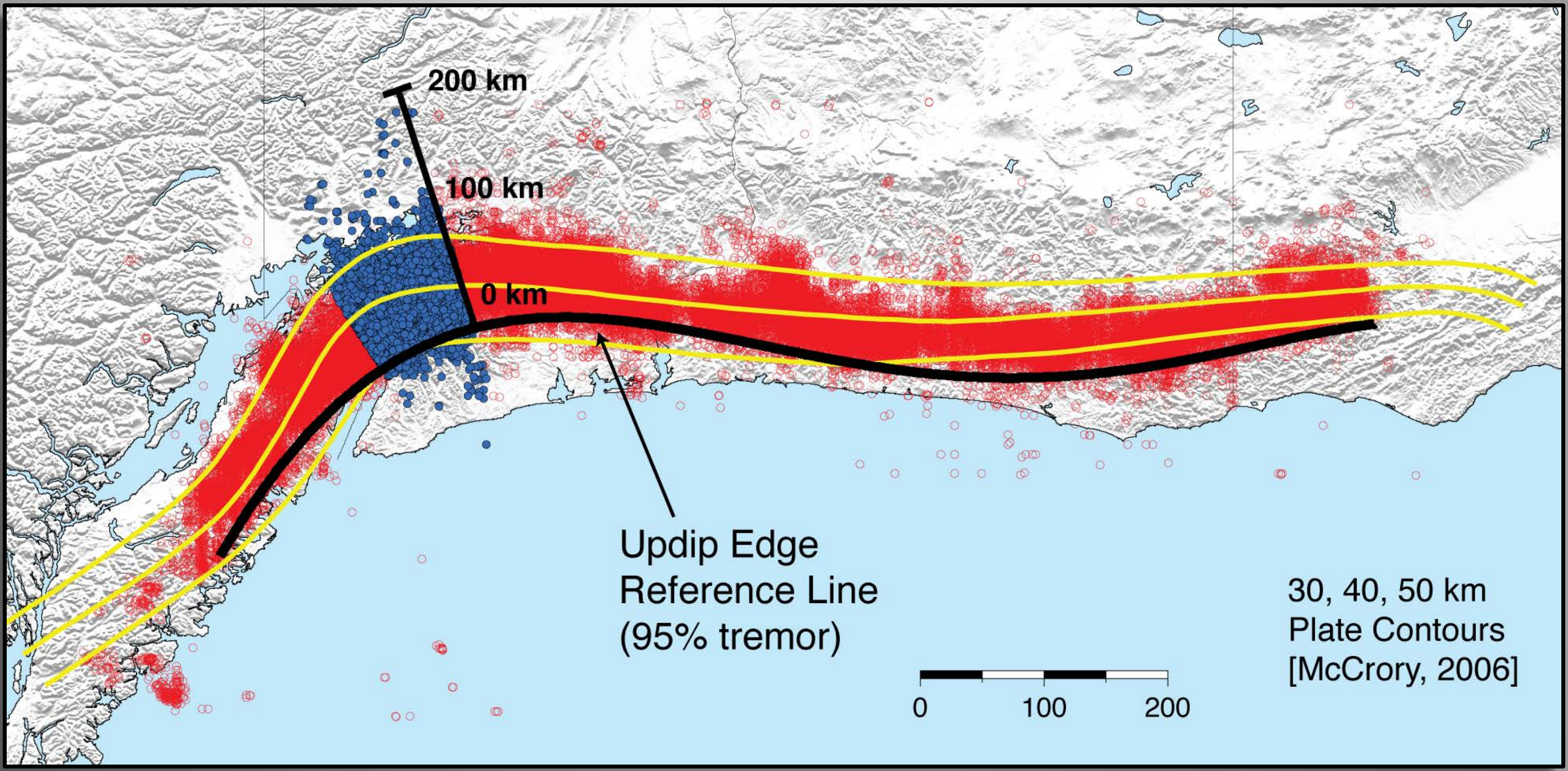
$\log_{10}N = a10^{-bM_w}$

b=1.0

if moment proportional to duration

Wech, Creager, Houston, Vidale; GRL, 2010

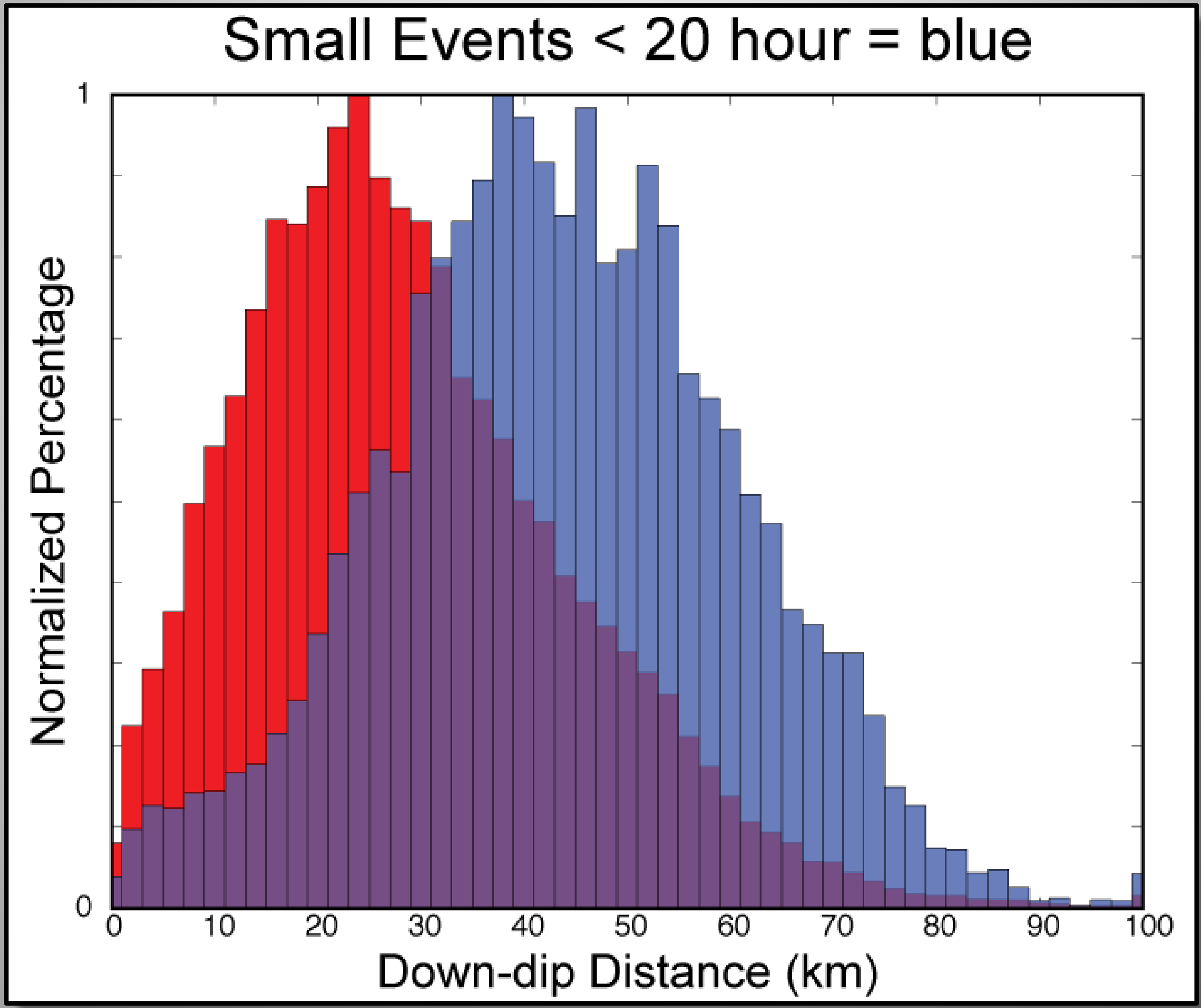
Reference line



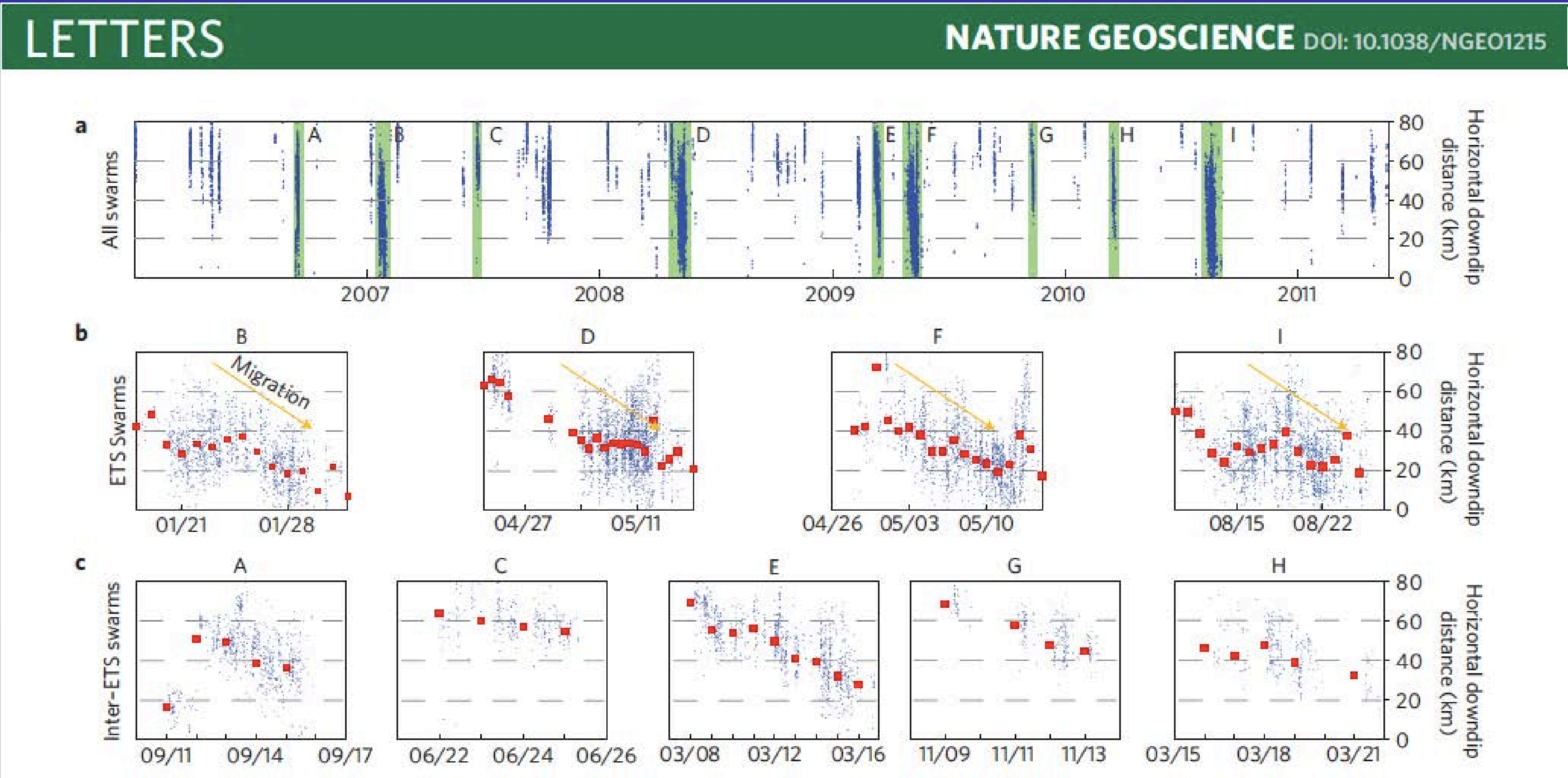
Blue dots = Study area

- Longest, most complete data set
- Shallowest plate dip

Large vs. small

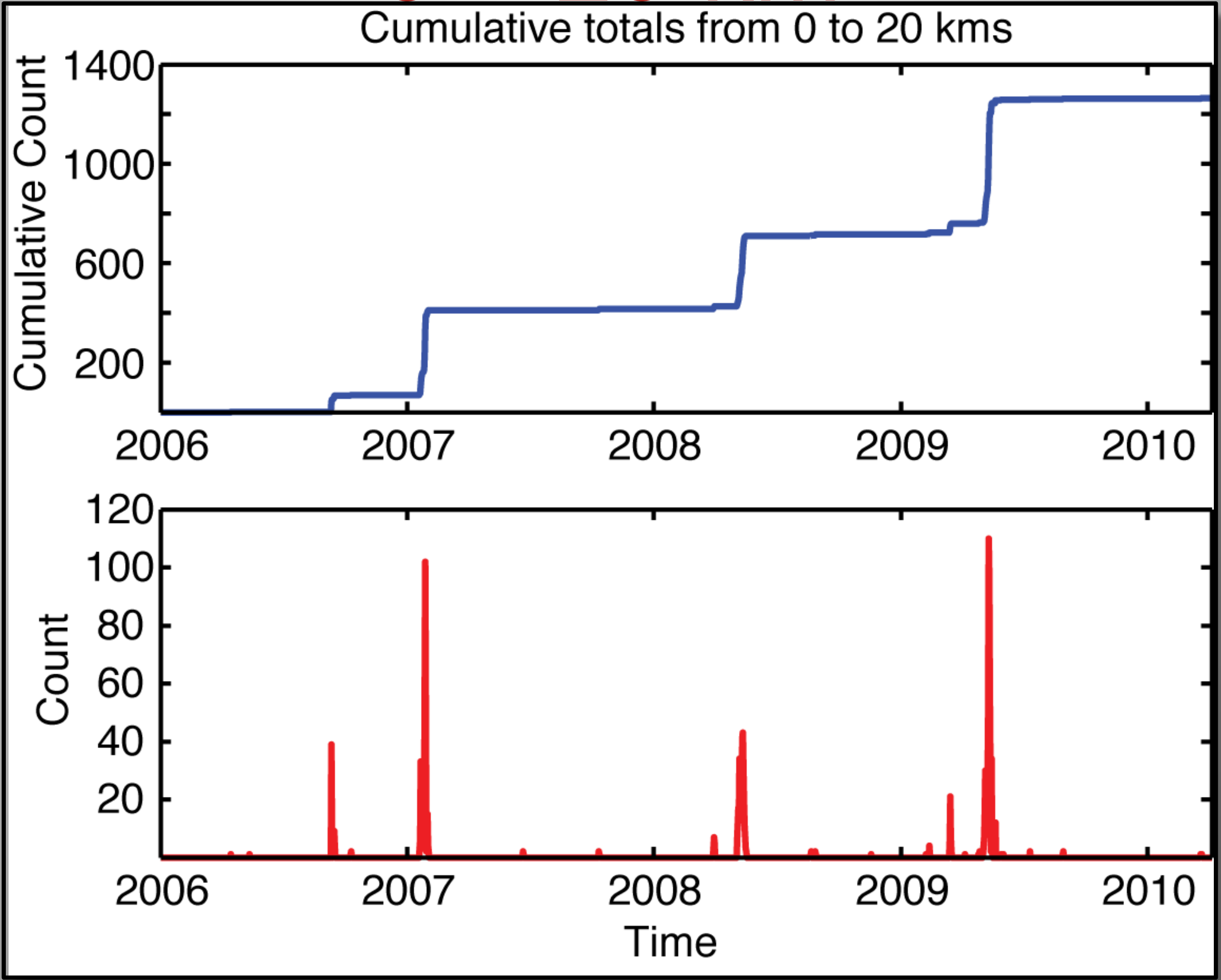


Up-Dip Migration



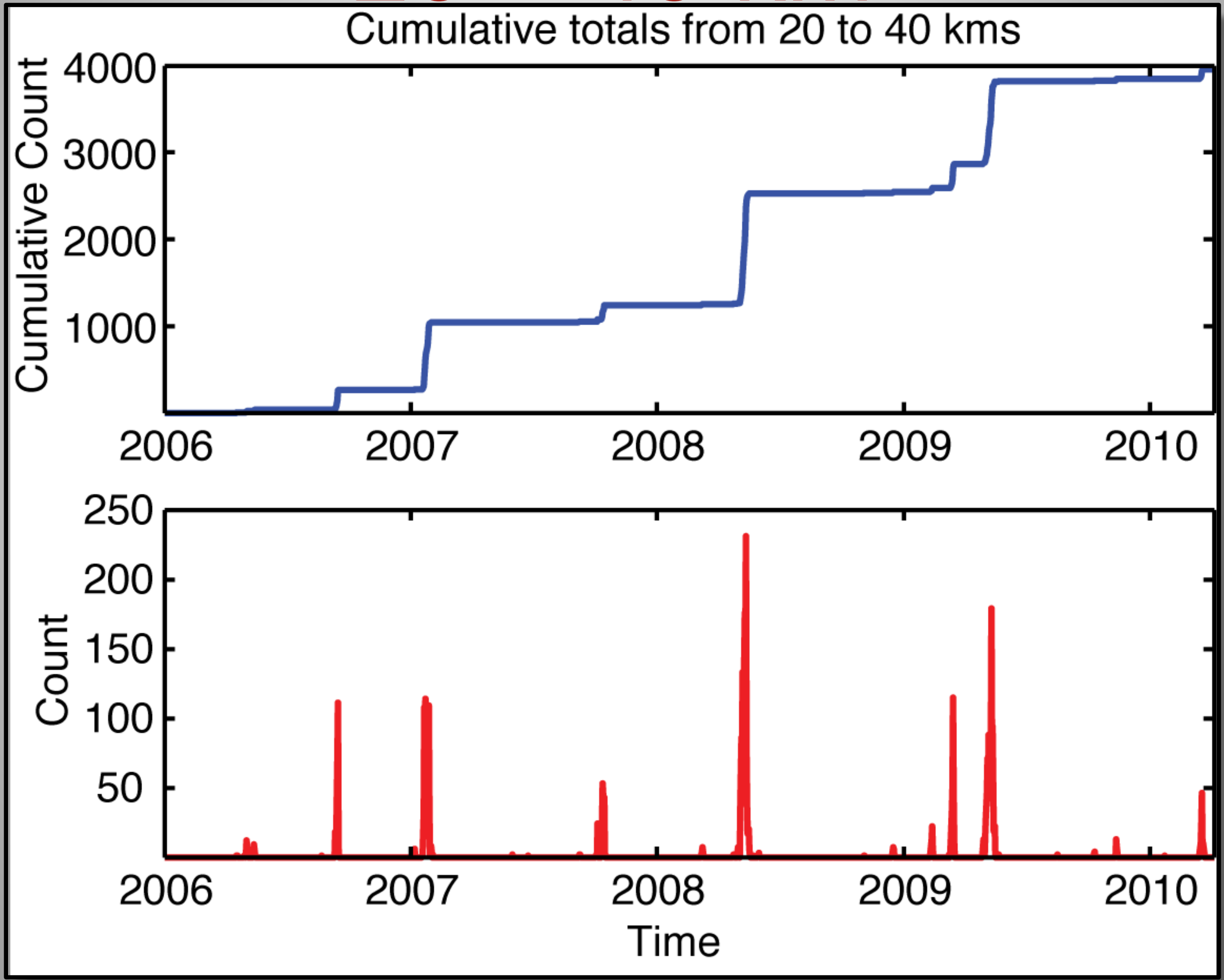
Wech and Creager, Nature GeoSci, 2011

0 – 20 km

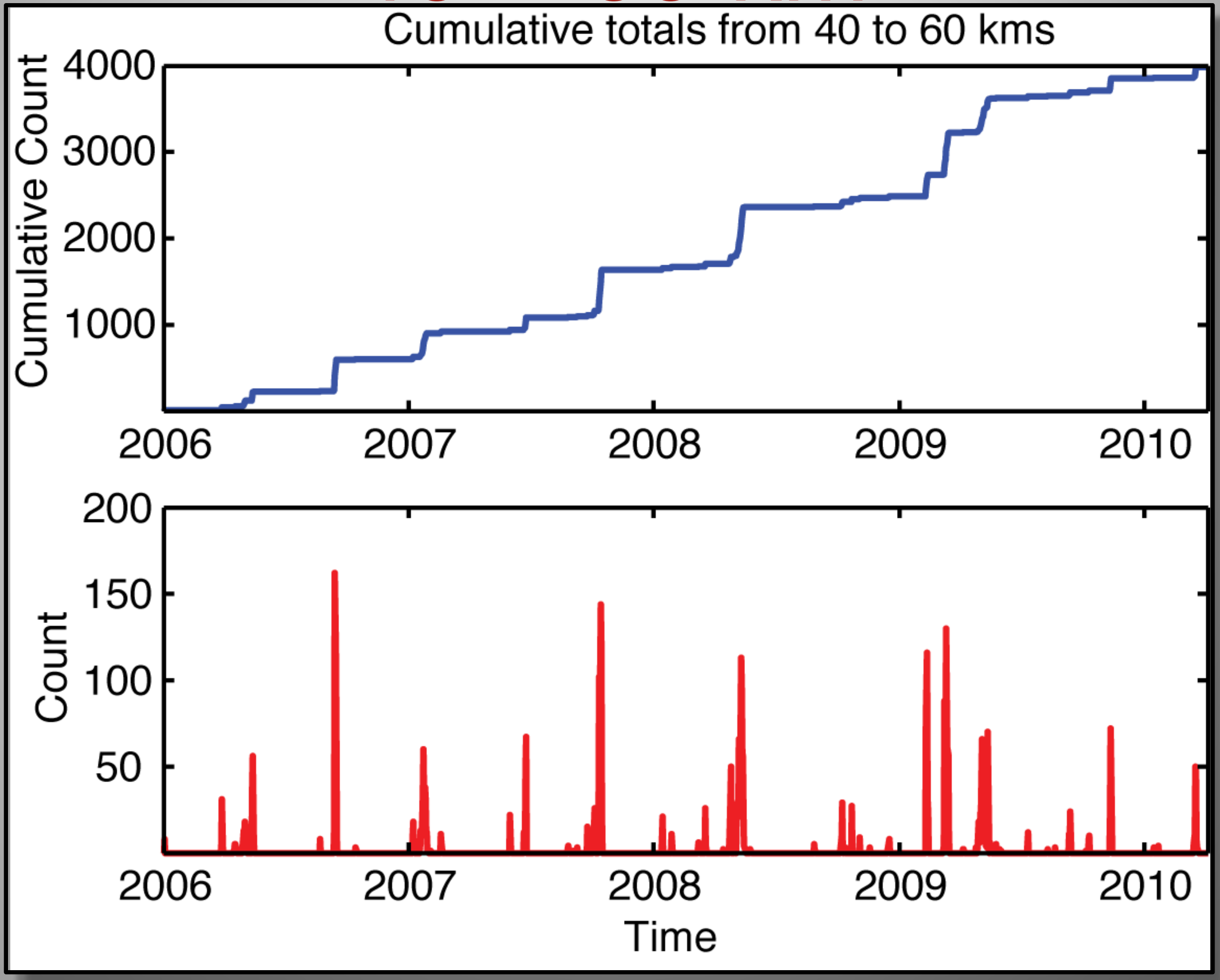


Cumulative totals from 0 to 20 kms
Cumulative Count
1400
1000
600
200
2006
2007
2008
2009
2010
Count
120
100
80
60
40
20
2006
2007
2008
2009
2010
Time

20 – 40 km

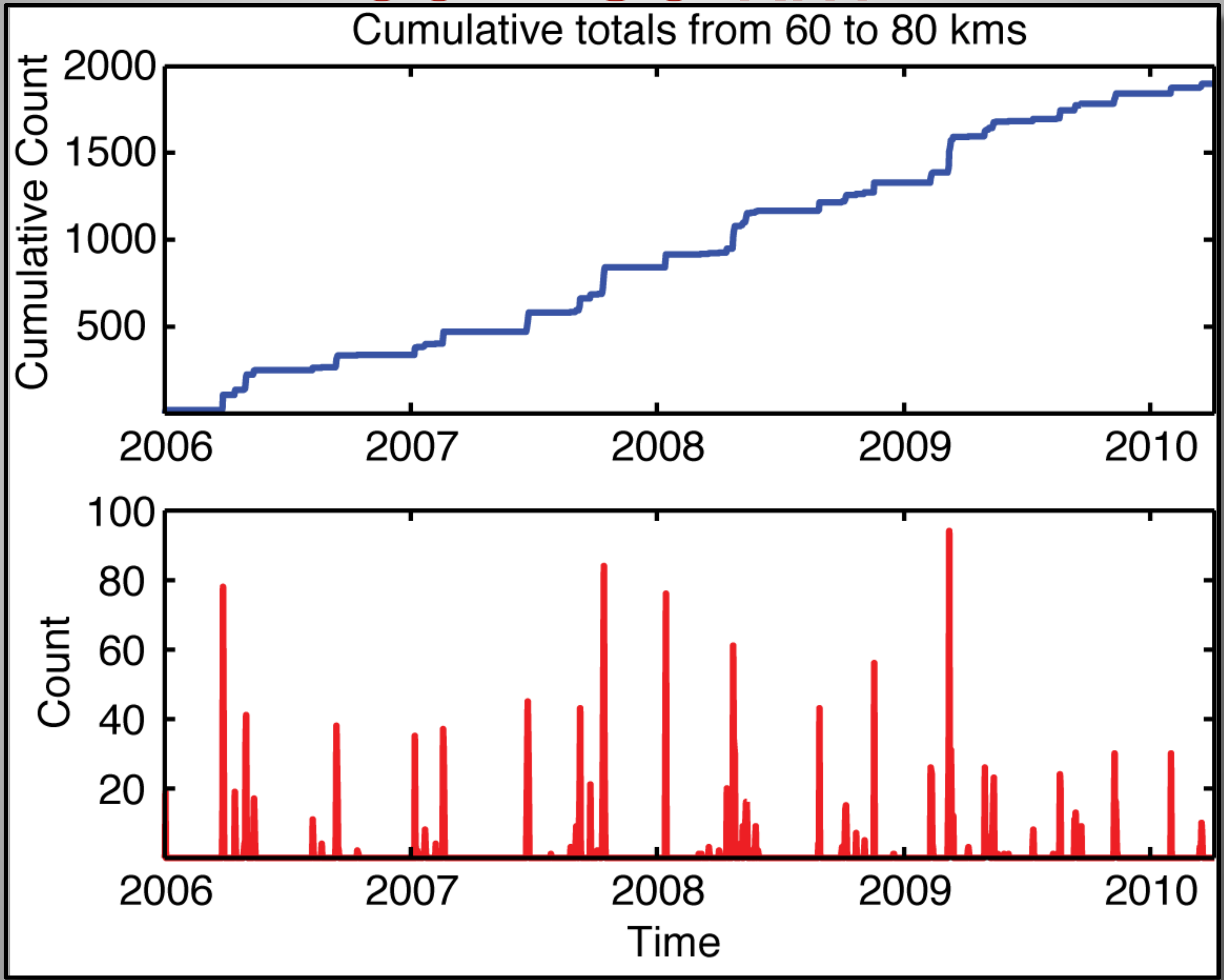

Cumulative totals from 20 to 40 kms
Cumulative Count
4000
3000
2000
1000
2006
2007
2008
2009
2010
250
200
150
100
50
Count
2006
2007
2008
2009
2010
Time

40 – 60 km



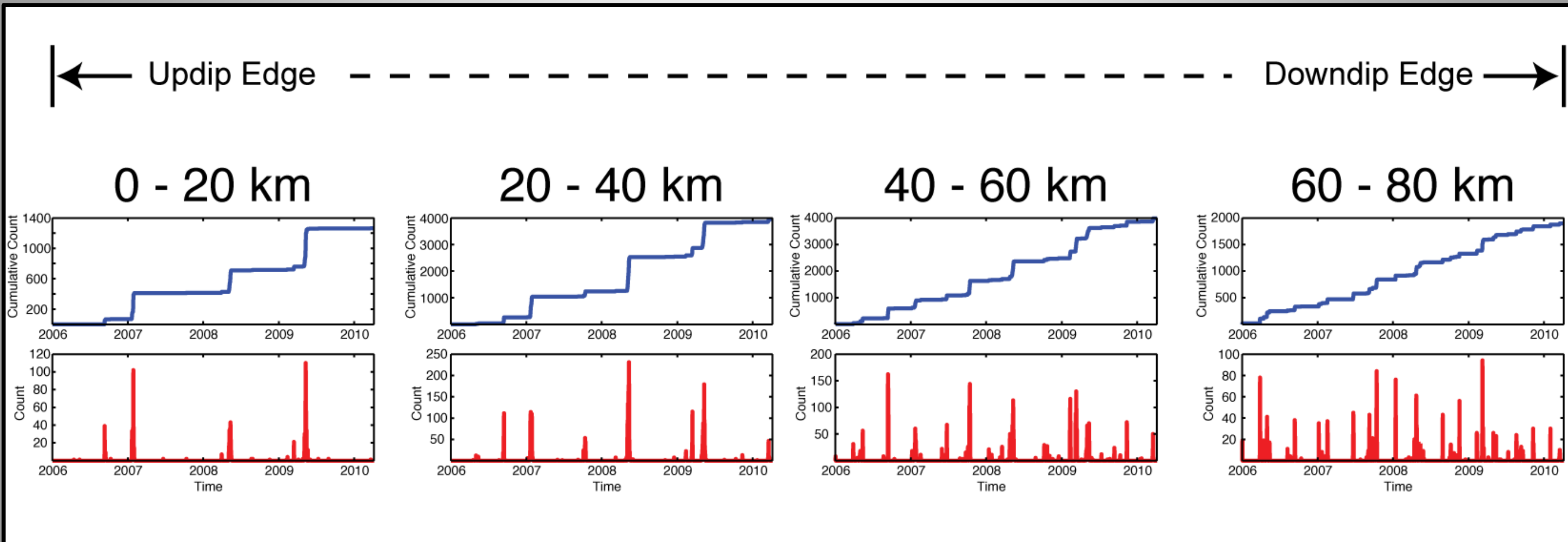
Cumulative totals from 40 to 60 kms
Cumulative Count
4000
3000
2000
1000
2006
2007
2008
2009
2010
200
150
100
50
Count
2006
2007
2008
2009
2010
Time

60 – 80 km



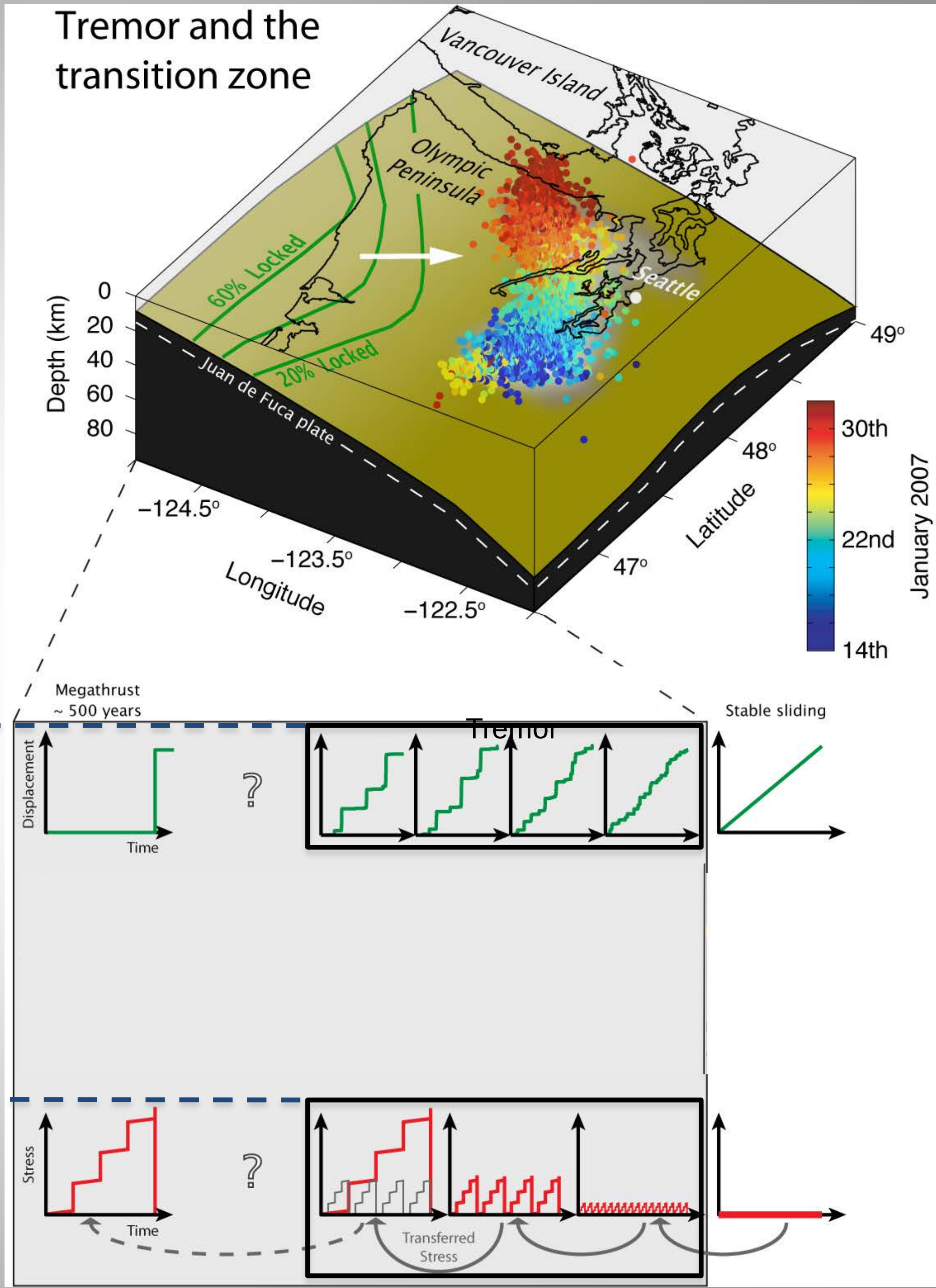
Cumulative totals from 60 to 80 kms
Cumulative Count
2000
1500
1000
500
2006
2007
2008
2009
2010
100
80
60
40
20
Count
2006
2007
2008
2009
2010
Time

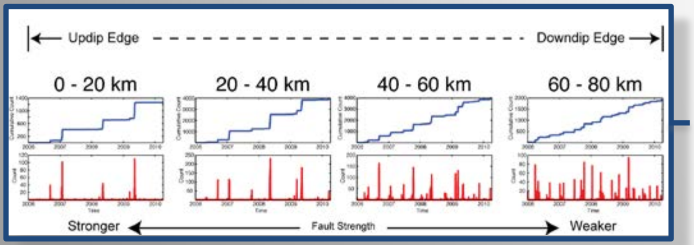
Profile

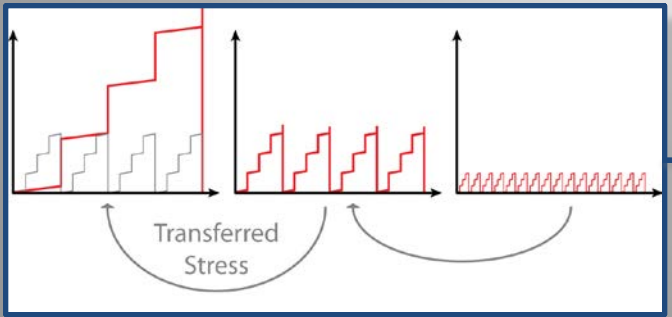


Updip Edge
Downdip Edge
0 - 20 km
20 - 40 km
40 - 60 km
60 - 80 km
Cumulative Count
Count
Time
2006
2007
2008
2009
2010

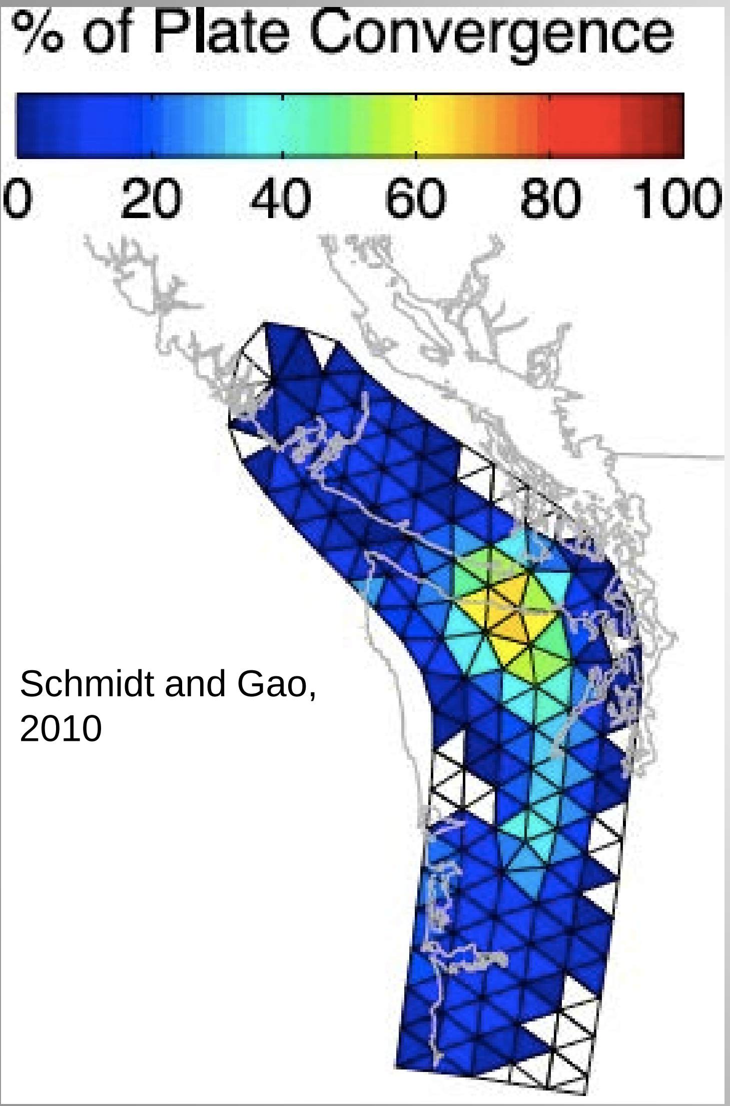
Episodic Tremor and Slip (ETS) role in Cascadia?



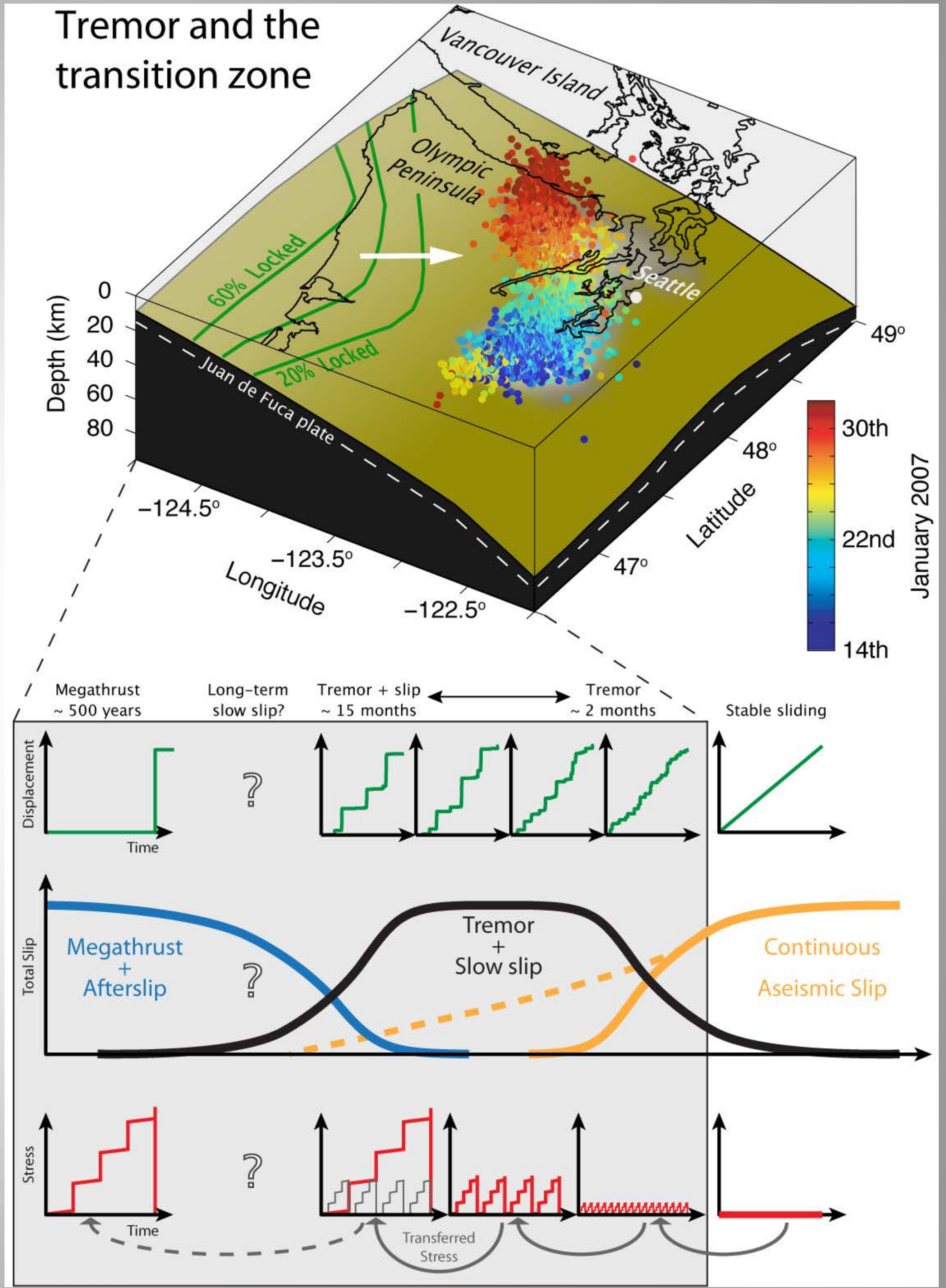




Tremor in Cascadia

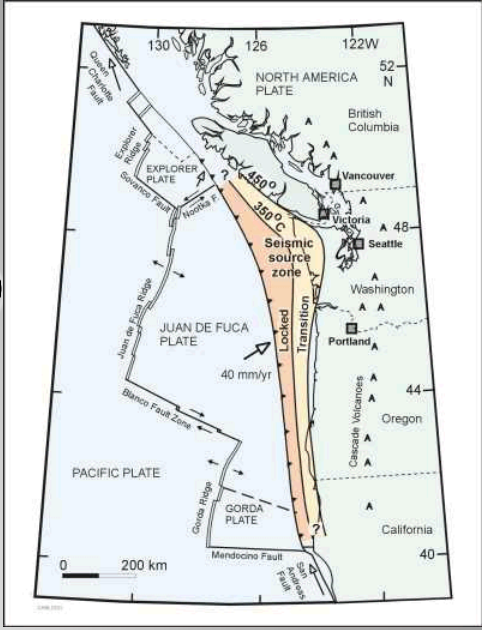


Schmidt and Gao, 2010



Conclusions

- Tremor clusters in space and time to form swarms
- Large tremor swarms correlate with geodeic slow slip (ETS)
- Tremor initiates down dip and propagates updip
- Nucleation phase takes about 5 days
- Followed by 10 km/day along-strike propagation
- Gradation from frequent small tremor swarms downdip to large infrequent slip updip
- Explained by stable sliding at depth and up-dip stress transfer from each slip event
- Swarms follow Gutenberg-Richter logarithmic frequency-magnitude relation
- Tremor amplitudes strongly modulated by tides and stress from surface waves -> weak fault
- Low Frequency Earthquakes:
  - 100 events within 200 meters of each other, suggests small source size
  - Duration up to 2 s, suggests propagation velocity < 100 m/s
- Tremor locates at plate interface and consistent with thrust mechanism



Dragert