Seismicity Rates from GPS and other Deformation Rate Estimates in Washington State

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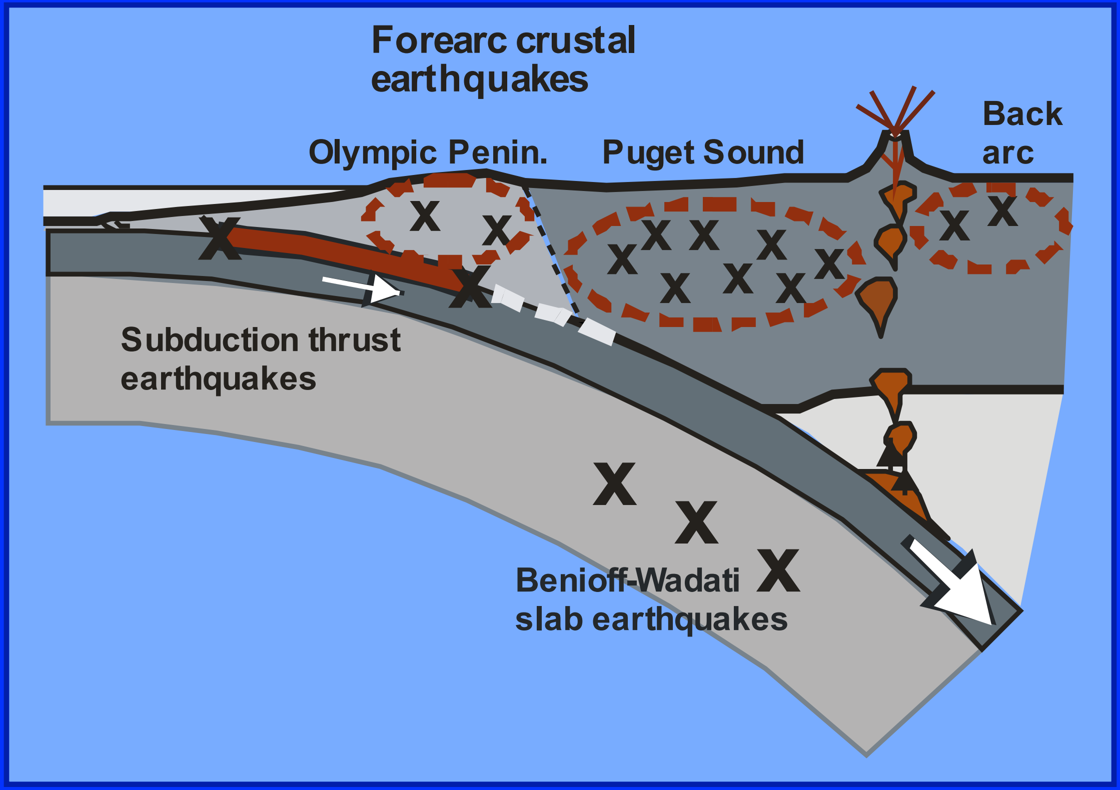
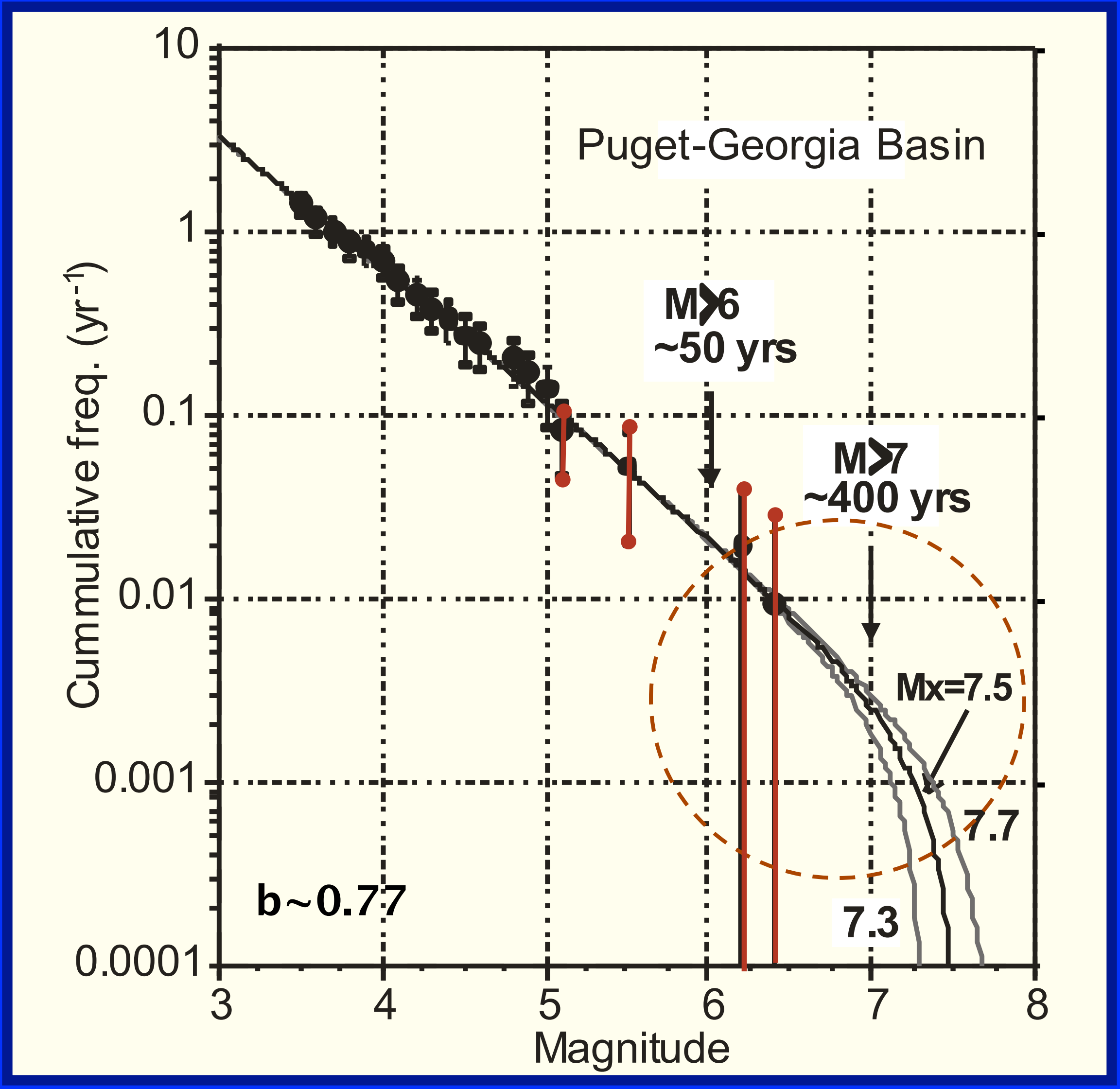


Catalogue Seismicity Rates

Large event rates based on smaller event rates

Are there large events without corresponding smaller magnitude seismicity?
i.e., "characteristic earthquakes"?

Cascadia megathrust
& central Van. Is.
two M7 with little other seismicity



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<u>Long-term Crustal Seismicity Rate in Pacific Northwest</u>

--Can we estimate the earthquake rate from that required to accommodate deformation rate <u>assuming all seismic?</u>
(GPS, paleoseismic fault displacement rates, tectonic models, etc.)

(1) Puget Sound, (2) Olympic Penin., (3) E. Washington

--Problem of short duration of catalogue seismicity; possibility of large infrequent earthquakes where few smaller ones, i.e., Cascadia megathrust, M7 central Van. Is. events, etc.
"characteristic earthquakes"?

--also issue of large crustal events in Puget Sound after megathrust as predicted by deformation data

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Seismicity rate from deformation rate

(Kostrov, 1974; Anderson, 1979; Hyndman & Weichert, 1983; Hyndman et al., 2003; Mazzotti et al., 2011)

Convergence Rate: $s' = C\, M_o' / (2\, \mu\, A')$

where:

A' = WL is the total cross-sectional area (i.e., need seismic thickness)

Mo' = rate of seismic moment release per unit time in area, from recurrence

Mo from magnitude vs moment relation

μ = shear modulus

C = faulting orientation constant, ~1.0 for 45° faulting

From Hyndman et al. (2003). Better to use strain rates rather than uniaxial shortening but less intuitive, e.g., detailed discussion by Mazzotti et al. (2011)

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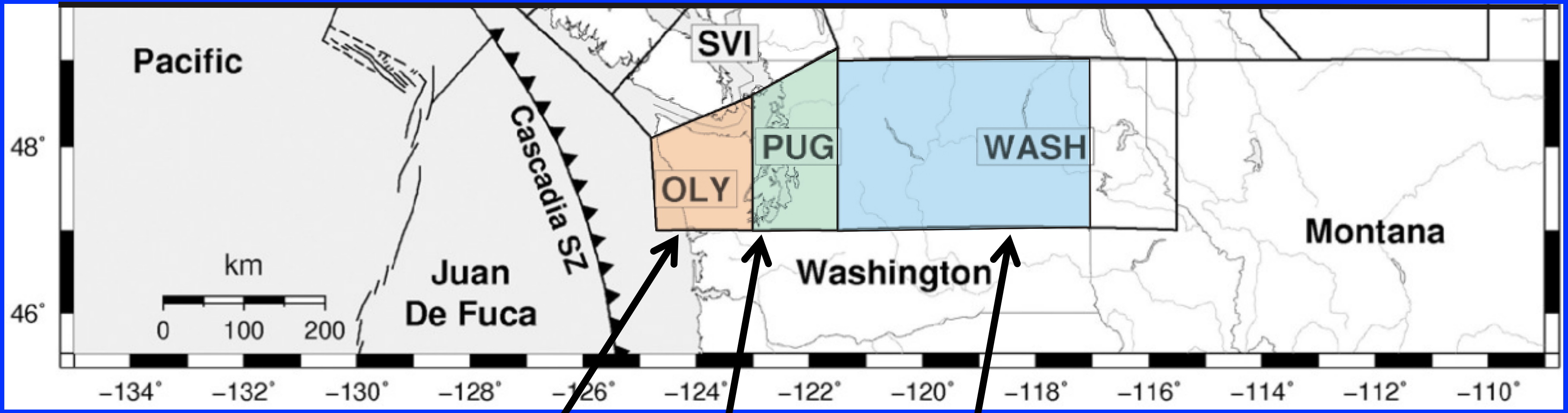
Washington Seismicity Areas Studied

(mainly from Mazzotti et al., 2011; *study with BC Hydro for mainly BC)*



Olympic Peninsula

Puget Sound

North-Eastern Washington

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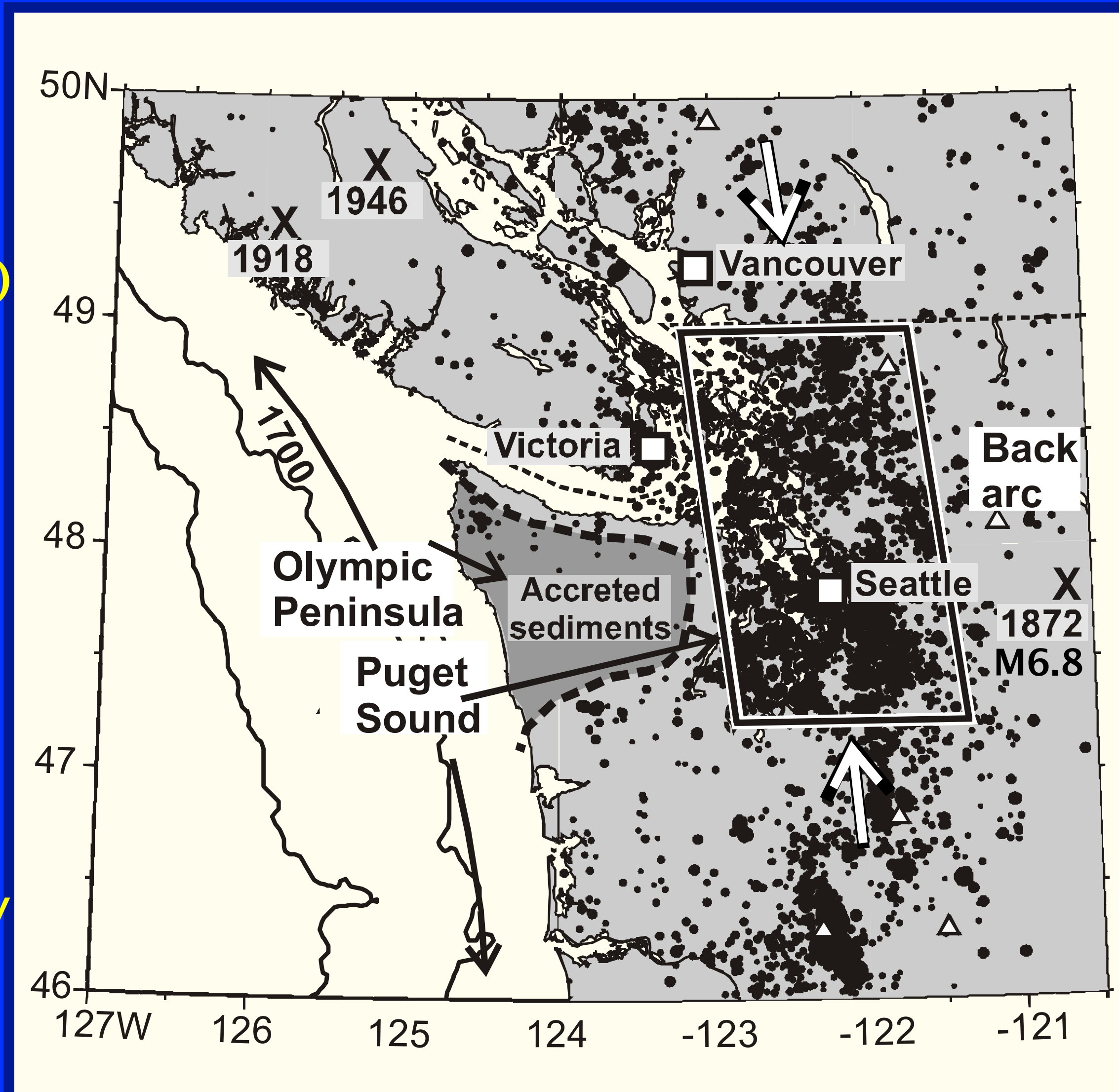
Crustal Seismicity Study Areas

Comparison of long-term seismicity rate from catalogue seismicity and from deformation (GPS etc)

1. Puget Sound
High seismicity, high deformation rate

2. Olympic Peninsula
Low seismicity, high deformation rate

3. Eastern Washington
Low seismicity, moderately low deformation rate



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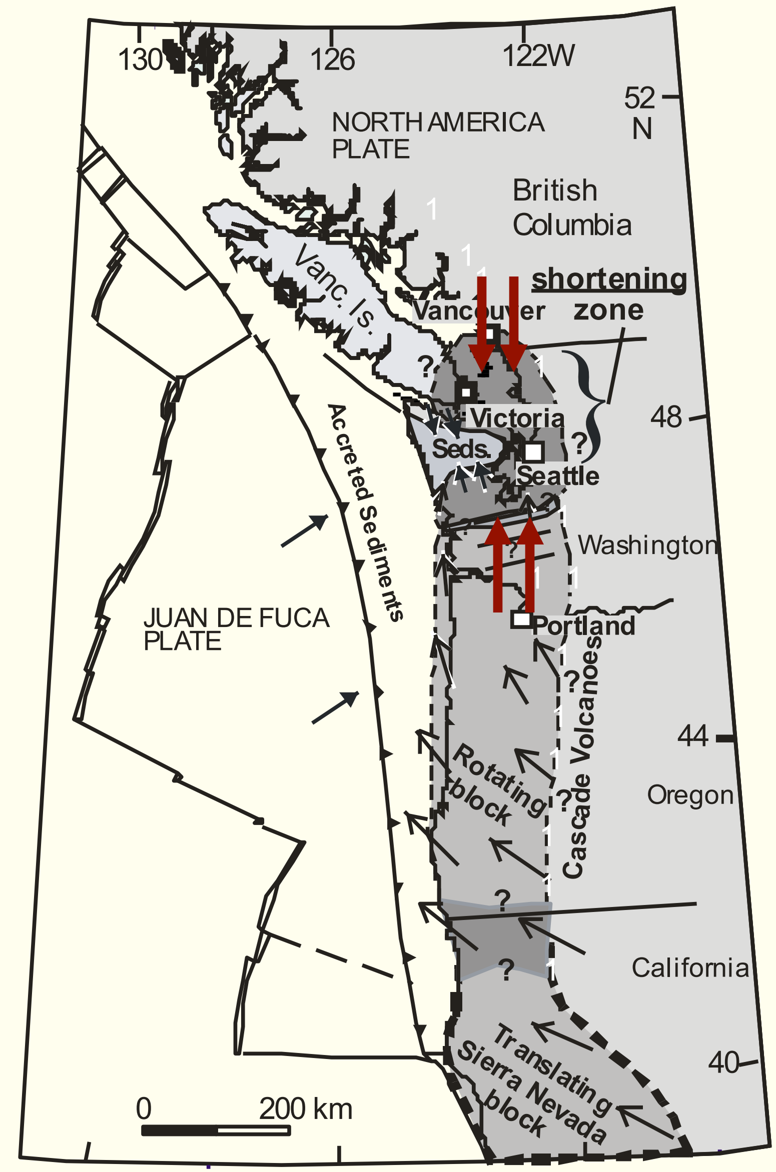
Puget Sound & Olympic Penin. N-S Deformation

Oregon forearc block is rotating northward compressing Puget Sound against Vancouver Island backstop
(Wells &Simpson, McCaffrey, and others)

Weak Olympic accr. sediments focus forearc deformation in Puget area



Modified from Wells and Simpson (200

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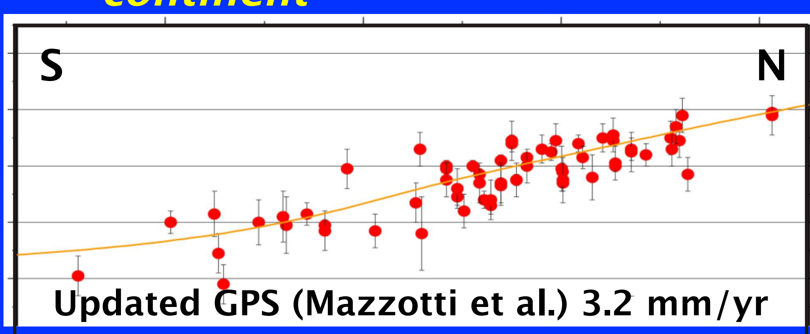
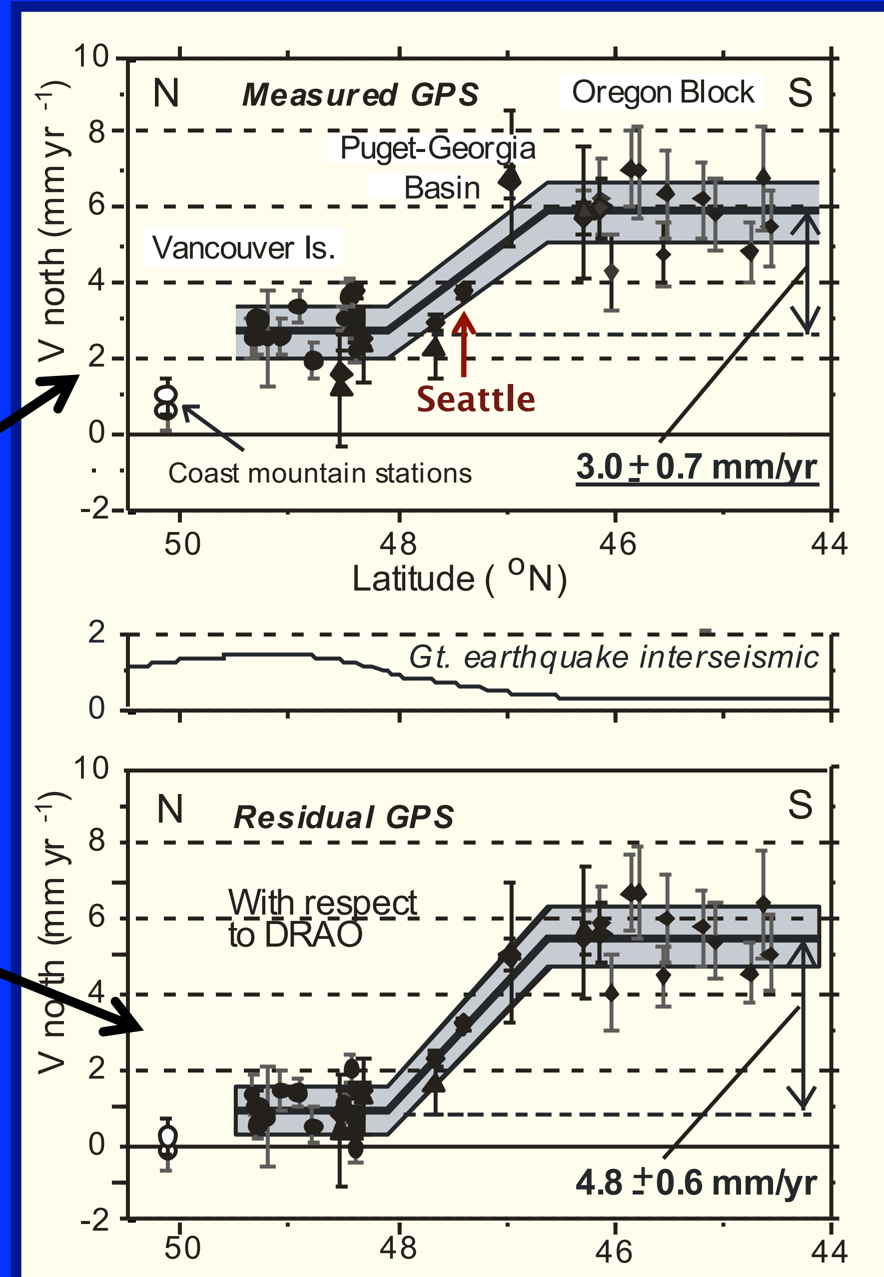
Puget Sound N-S Deformation Rate from GPS

Stable continent reference

Current rate relative to Vancouver Island
(which is moving north due to great earthquake cycle elastic deformation)

Long-term through great earthquake cycle
i.e., relative to stable continent





(Hyndman et al., 2003)

N–S Shortening Rates for Puget Sound Area

1. GPS shortening rate (Sherrod, Mazzotti, Haugerud, 2008; Hyndman et al., 2003):
Current: 3.2 ± 0.8 mm/yr: Long-term: 4.8 ± 0.6 mm/yr

2. GPS rotation models for Oregon Block (e.g., McCaffrey et al., 2007):
Puget Sound northerly motion: 4.4 ± 0.3 mm/yr.

3. Paleomagnetic models (e.g., Wells et al., 1998; Wells and Simpson, 2001):
Northerly motion of southern Puget Sound: ~6 mm/yr

4. Active fault estimates: total north-south rate: 3.6 mm/yr
(Sherrod, Mazzotti, & Haugerud, 2008; Wells and Simpson, 2001);
Seattle fault: 0.7-1.1 mm/yr, Johnson et al., 1999)

***What seismicity rate is required to accommodate this deformation rate** (assuming all seismic)?*

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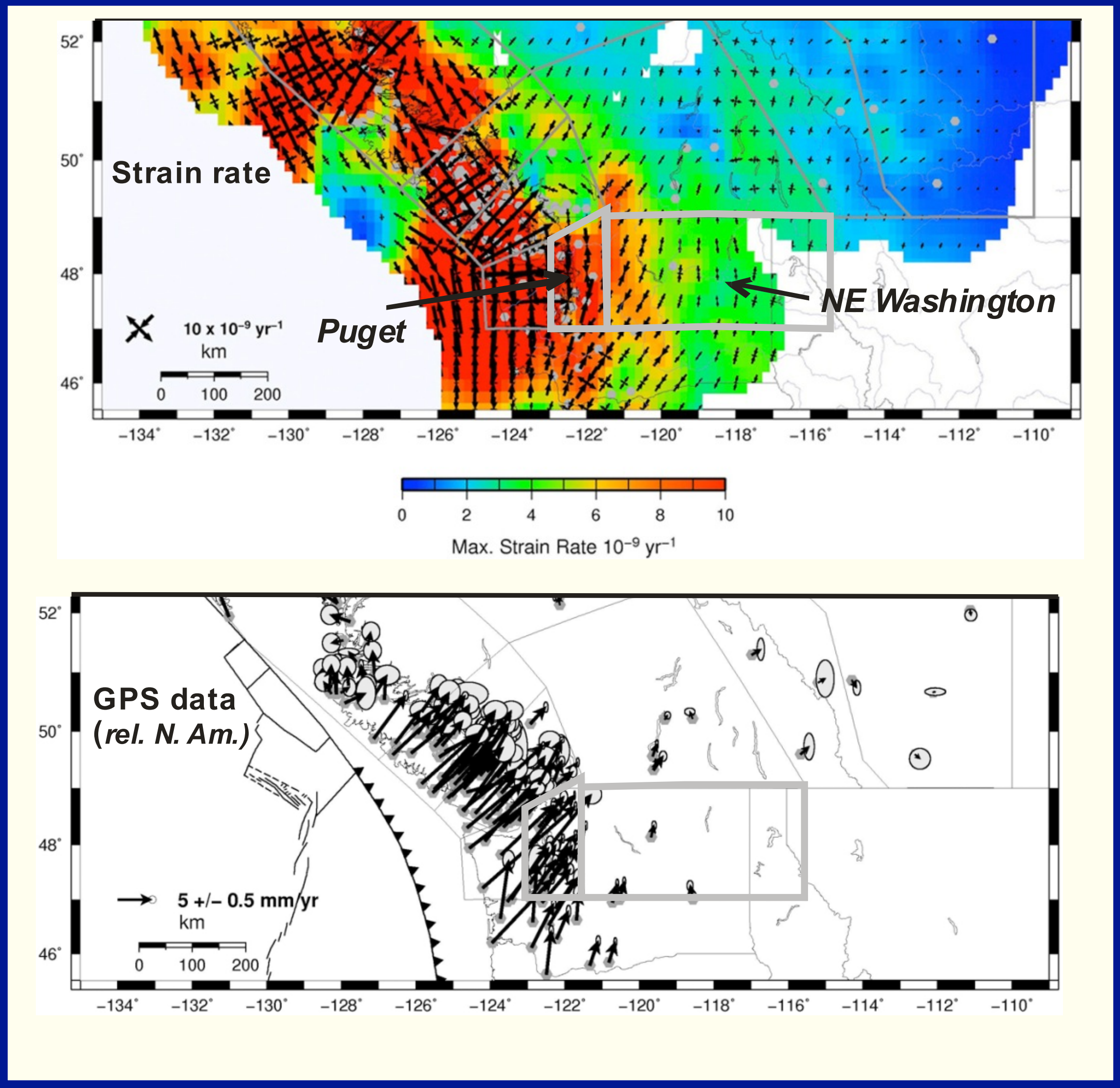
GPS Data and Strain Map of Pacific Northwest

(Mazzotti et al., 2011)



Estimate smoothed strain field
(not just shortening)

Estimate seismicity rate required to accommodate strain

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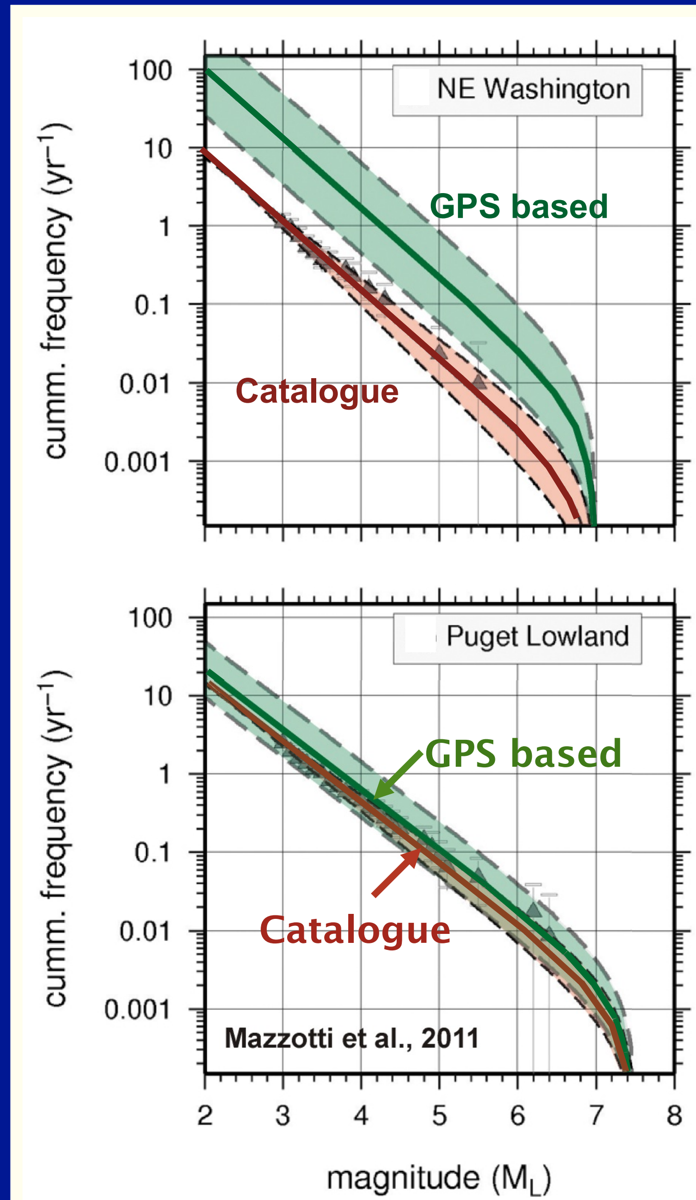
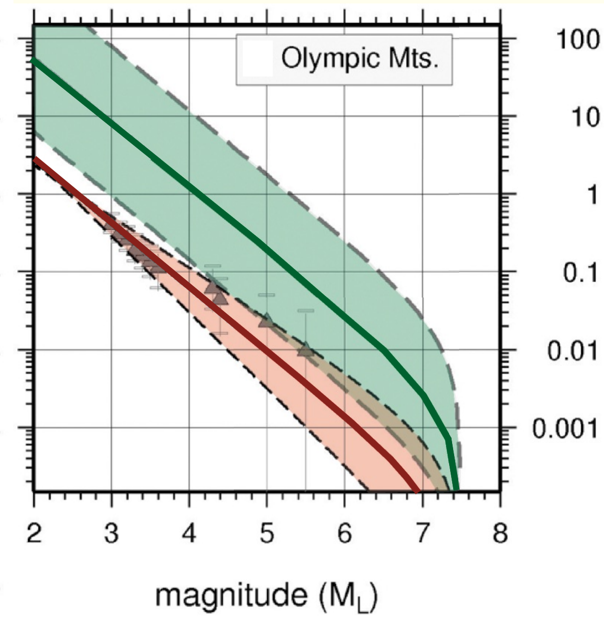
Seismicity Rate from GPS strain rate

(Mazzotti et al., 2011):

Puget-Sound agrees well with catalogue

E. Washington & Olympic Penin. much greater than catalogue (x10)





Extra seismicity could be spread over all magnitudes (recurrence in figures), or accommodated by a number of ~M7 "characteristic" earthquakes

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Moment Rates from Catalogue Seismicity compared to from GPS Strain

(Mazzotti et al., 2011)

(10^{17} Nm yr^{-1})

	GPS	Seismicity	Ratio
Puget Sound	2.8	2.2	~ 1
Olympic Mtns.	4.1	0.23	18
E. Washington	1.9	0.20	10

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Olympic Peninsula and Central/Eastern Washington Seismicity Rates from GPS Data

1. Catalogue seismicity for Puget Sound agrees well with estimate from deformation

2. Large N-S shortening rate for Olympic Peninsula (greater than for Puget Sound) but very little seismicity. Is deformation mainly aseismic in this accretionary sedimentary prism (as in such prisms elsewhere)?

3. Seismicity for Eastern Washington required to accommodate GPS strain is much greater than that in the catalogue. This is a common occurrence for low deformation rate areas. Explanation unclear; aseismic?

But, more frequent large events than indicated by the catalogue cannot be excluded. ... low weighting?

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Good agreement of deformation estimates and catalogue seismicity:

1. Puget Sound N–S shortening
2. San Andreas fault system
3. Queen Charlotte fault zone
4. Denali fault zone, Alaska
5. Offshore transform faults of J. de F. ridge
6. Charlevoix (eastern Canada seismic area)

Deformation estimates much greater:

Olympic Mtns, E. Washington, most of B.C. interior, other slow deformation examples; possible large "characteristic" events not shown by catalogue

Large recorded earthquakes with few smaller events:

Cascadia, Central Vancouver Island...

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Implications for PSHA: ratios of ground shaking derived from GPS vs seismic data

(Mazzotti et al. (2011)

Puget Sound: ~1:1   good agreement

Olympic Peninsula and E. Washington:

> 10 x seismicity; 2-3 times greater PGA from GPS-derived model compared to catalogue seismicity

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Conclusions:

(1) Can long-term seismicity rates be estimated quantitatively from deformation data? (GPS, fault slip rates, tectonic models, etc.)

Yes, but... probably only for areas with rapid deformation and well-organized "mature" faults or deformation zones *(Hypothesis?)*

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(2) Deformation confirms seismicity rates from catalogue for Puget Sound

--GPS deformation larger than seismic for Olympic Mtns. and E. Washington, so could have large "characteristic" events, but give low weighting?

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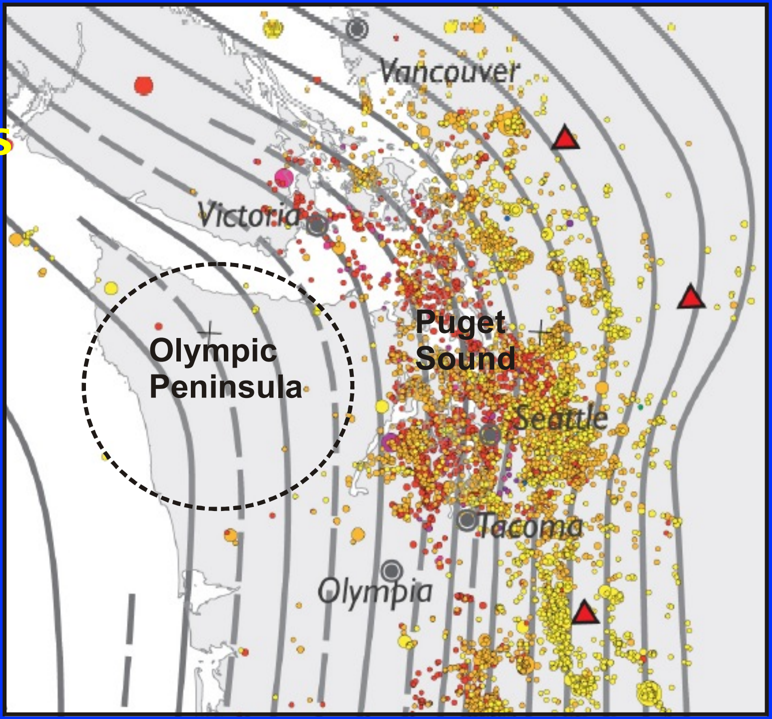
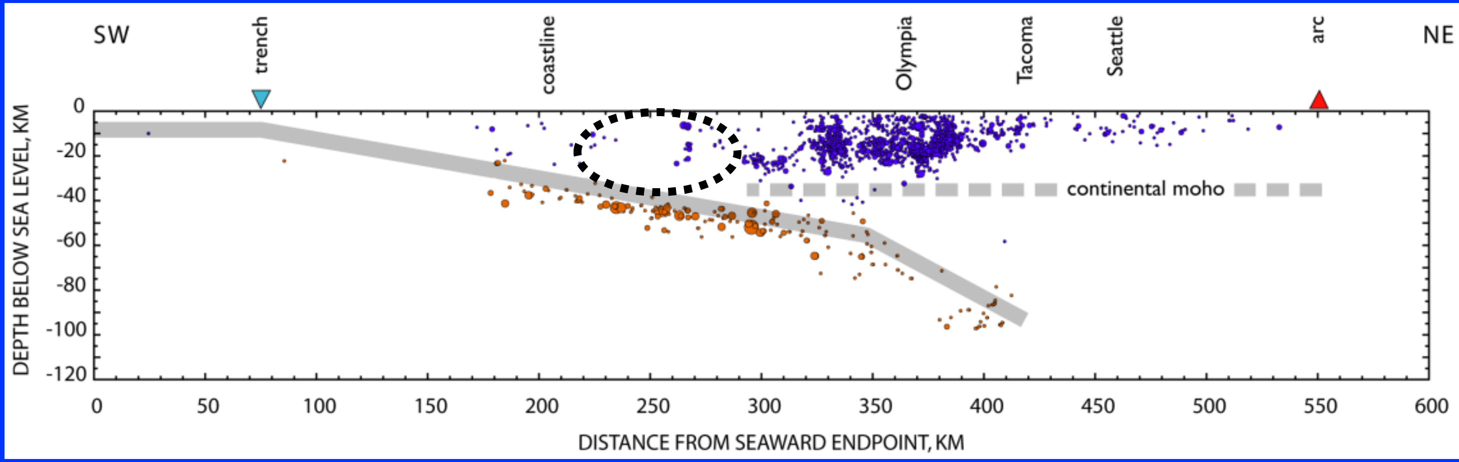
Very few catalogue earthquakes in Olympic Peninsula area





from McCrory et al.

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Puget Sound Seismicity Rates from Deformation Data

1. Seismicity rate to accommodate deformation is very close to rate from catalogue seismicity.

2. Vancouver Island receding to north due to locked megathrust elastic deformation. Will be recovered to south in megathrust. i.e., ~up to seven M > 7 events after megathrust possible.

Crustal events occurring some "short" time after megathrust could be more important hazard than the megathrust itself,

-but not really apparent in paleoseismic data?

Sherrod et al. conclude about half of Holocene shortening occurred over short time period (~1100 yrs ago), including Seattle fault earthquake M≥7 (1020-1050 cal yr BP, Atwater 1999). Timing does not appear to match a megathrust event.

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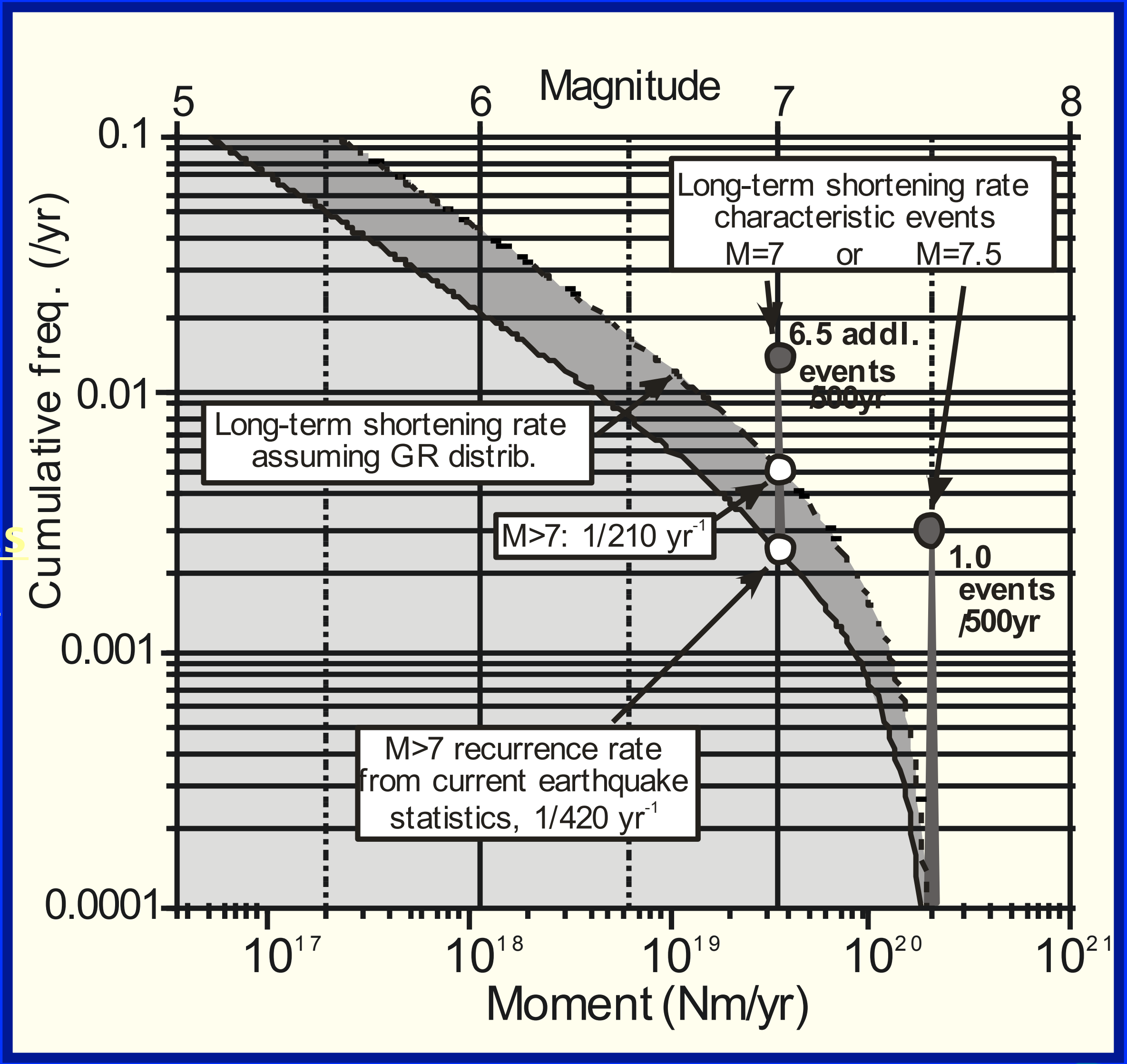
Long-term Deformation over Great Earthquake Cycle

South component of megathrust coseismic motion results in 0.5-1.0 m short-term N-S shortening

<u>~ 7 additional M=7 events following the megathrust</u> possible to accommodate this shortening?



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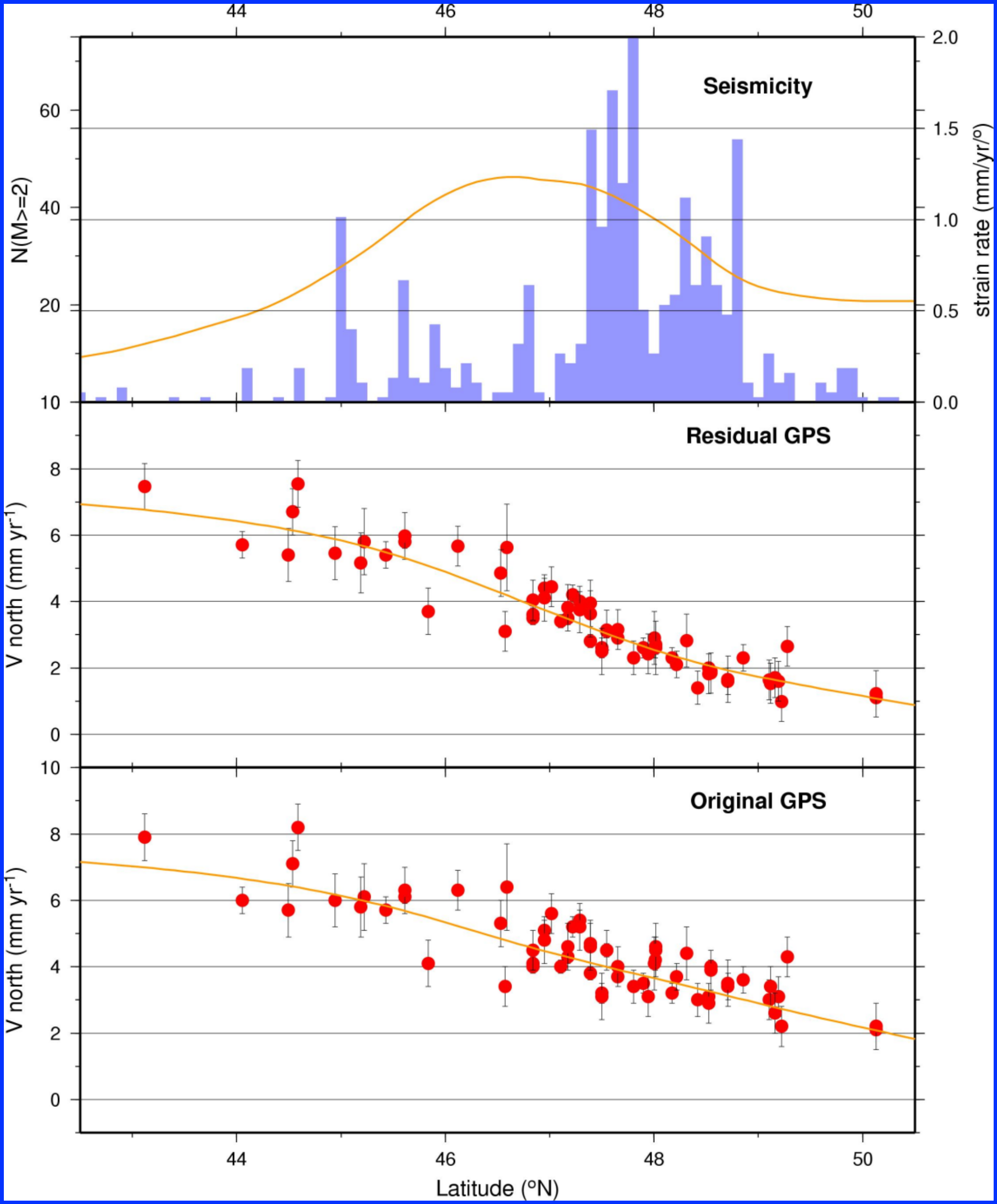
N-S GPS Puget Sound



Long-term through great earthquake cycle
i.e., relative to stable continent

Current rate relative to Vancouver Island
(which is moving north due to great earthquake cycle elastic deformation)

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