USGS Tools for Seismic Hazard Characterization

Art Frankel
U.S. Geological Survey
Seattle, WA
afrankel@usgs.gov

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Outline of Talk

- Review methodology of the National Seismic Hazard Maps (NSHM) and probabilistic seismic hazard assessment (PSHA)
- Describe new logic trees for M8-9 earthquakes on the Cascadia Subduction Zone (CSZ) used in the 2014 update of the NSHM's; compare 2014 and 2008 maps
- Describe tools on the USGS NSHM website that can be used for hazard characterization of a site
- Show strong ground-motion observations from the M9.0 Tohoku, Japan and M8.8 Maule, Chile earthquakes
- Summarize M9 project that is developing synthetic strong ground motions for Cascadia M9 earthquakes

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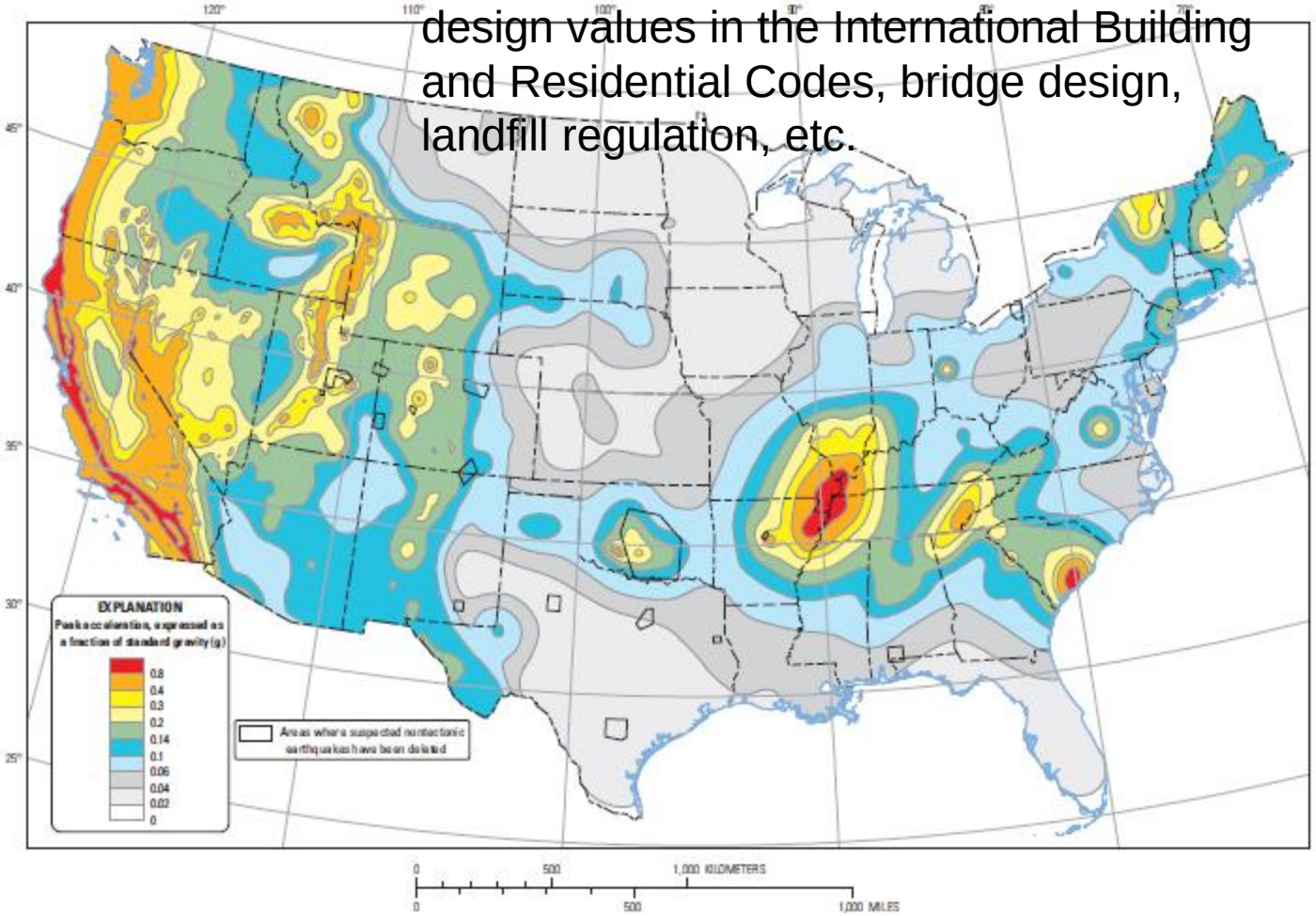
The national seismic hazard maps were updated in 2014 USGS Open-File Report 2014-1091 Petersen et al. earthquake.usgs.gov/hazards

These hazard maps are the basis for design values in the International Building and Residential Codes, bridge design, landfill regulation, etc.



Two-percent probability of exceedance in 50 years map of peak ground acceleration

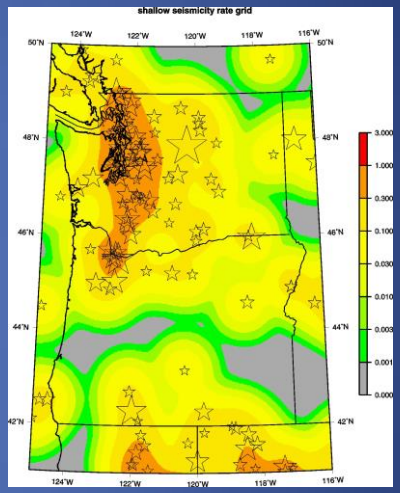
Seismic hazard assessment integrates what we know about earthquake sources, faults, deformation, and ground motions

STICK CLOSE TO THE DATA!

Geologic mapping, fault slip rates
EQ chronologies from paleoseismology
potential fields, seismic reflection/refraction

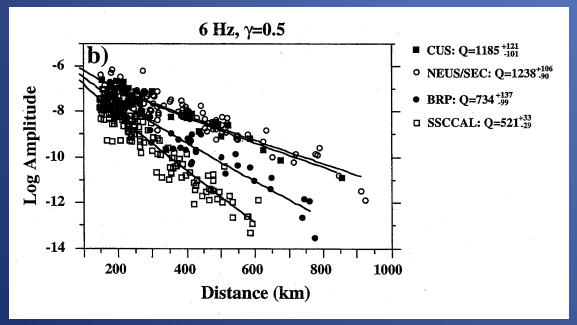
Photo from Nelson et al. (2003)

Earthquake catalogs (instrumental and historical), source parameters, ANSS. PNSN



National Seismic Hazard Maps (probabilistic seismic hazard assessment)

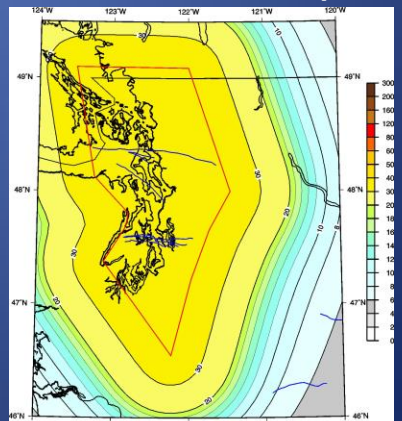
Seismograms: weak and strong motion (ANSS, CGS)
peak and spectral amps



From Benz et al. (1997)

Crustal deformation Measurements (GPS)

Hazard map based on 3mm/yr north-south convergence in Puget Sound region



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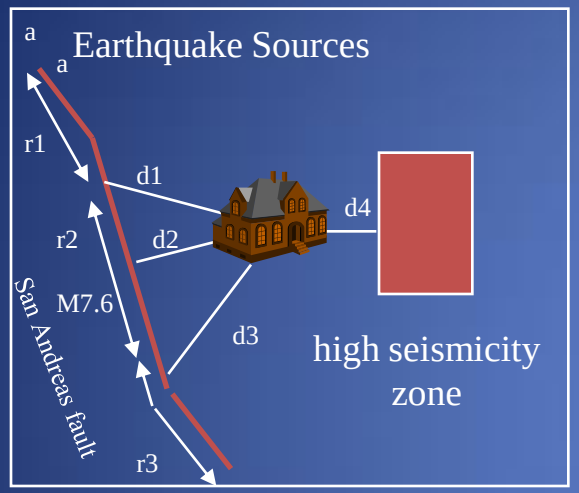
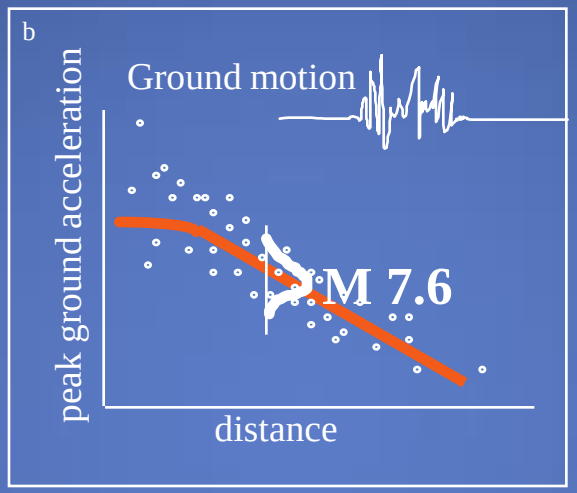
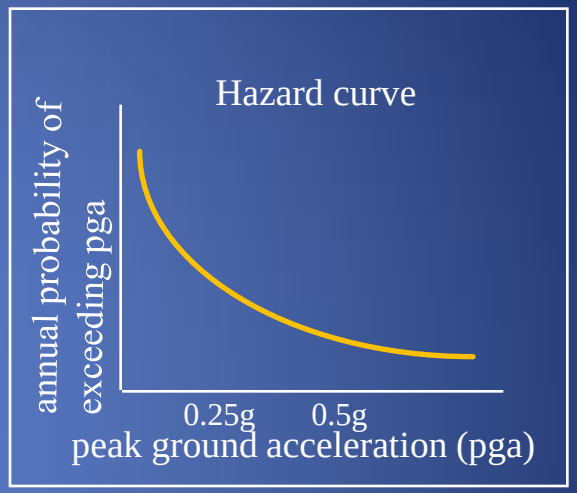
Hazard Methodology Example







Specify recurrence rates of earthquakes for each source that can affect site of Interest

Time independent or time dependent

Attenuation relations tell you median ground motions that each potential earthquake will produce at site, and variability

Derived from strong-motion data (WUS) or models (CEUS). Can include site amp and 3D sedimentary basin effects

Hazard curve: describes probability of having ground motions ≥ a certain intensity

We use mean hazard curves from logic trees with alternative models

Annual probability of having ground motions larger than some specified value U =

annual probability of earthquake occurring

X

probability of having ground motions larger than U when earthquake occurs

Recent PacNW Workshops for the 2014 Update of the NSHM's

- November 18-19, 2010, Corvallis, to evaluate turbidite data for constraining CSZ recurrence rates and magnitudes (USGS OFR 2011-1310)
- December 15, 2011, Eugene, to evaluate models for eastern edge of CSZ rupture zones
- March 21-22, 2012, Seattle, to gather inputs and feedback for the update of the NSHM's
- December 13, 2012, Berkeley to discuss WUS ground-motion prediction equations including those for Cascadia great earthquakes

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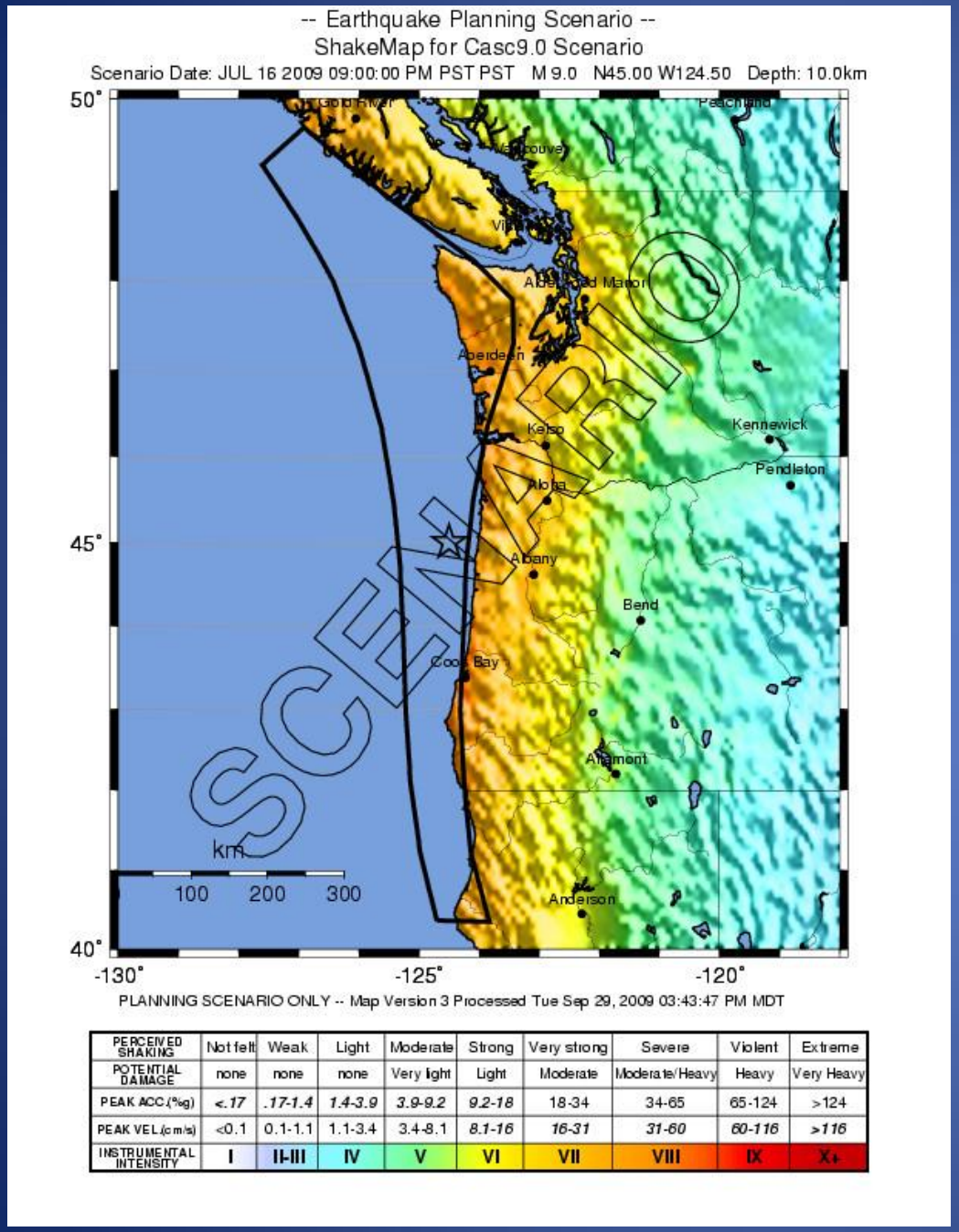

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scientific consensus is that these M8.8-9.2 earthquakes occur about every 530 years, on average

Last one was in 1700

Estimate a 10-14% chance of occurring in the next 50 years

We also include possibility of M8 earthquakes anywhere along the subduction zone.

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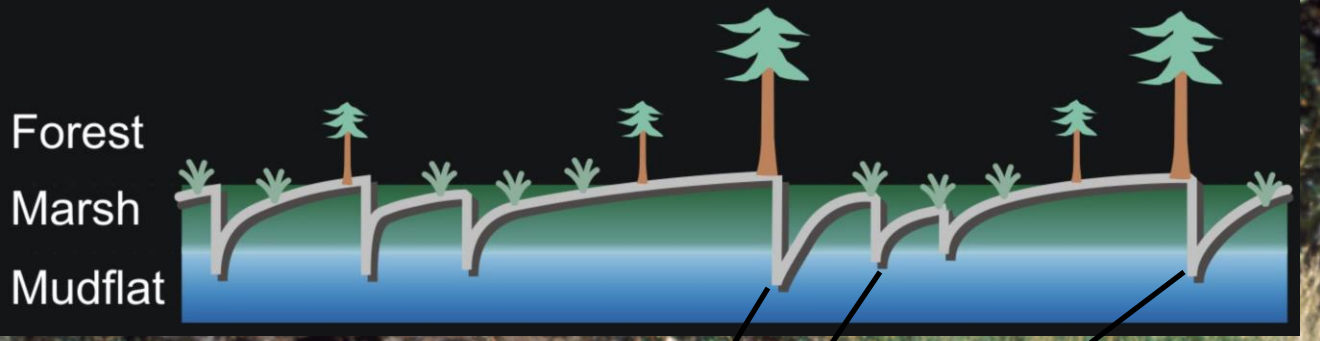

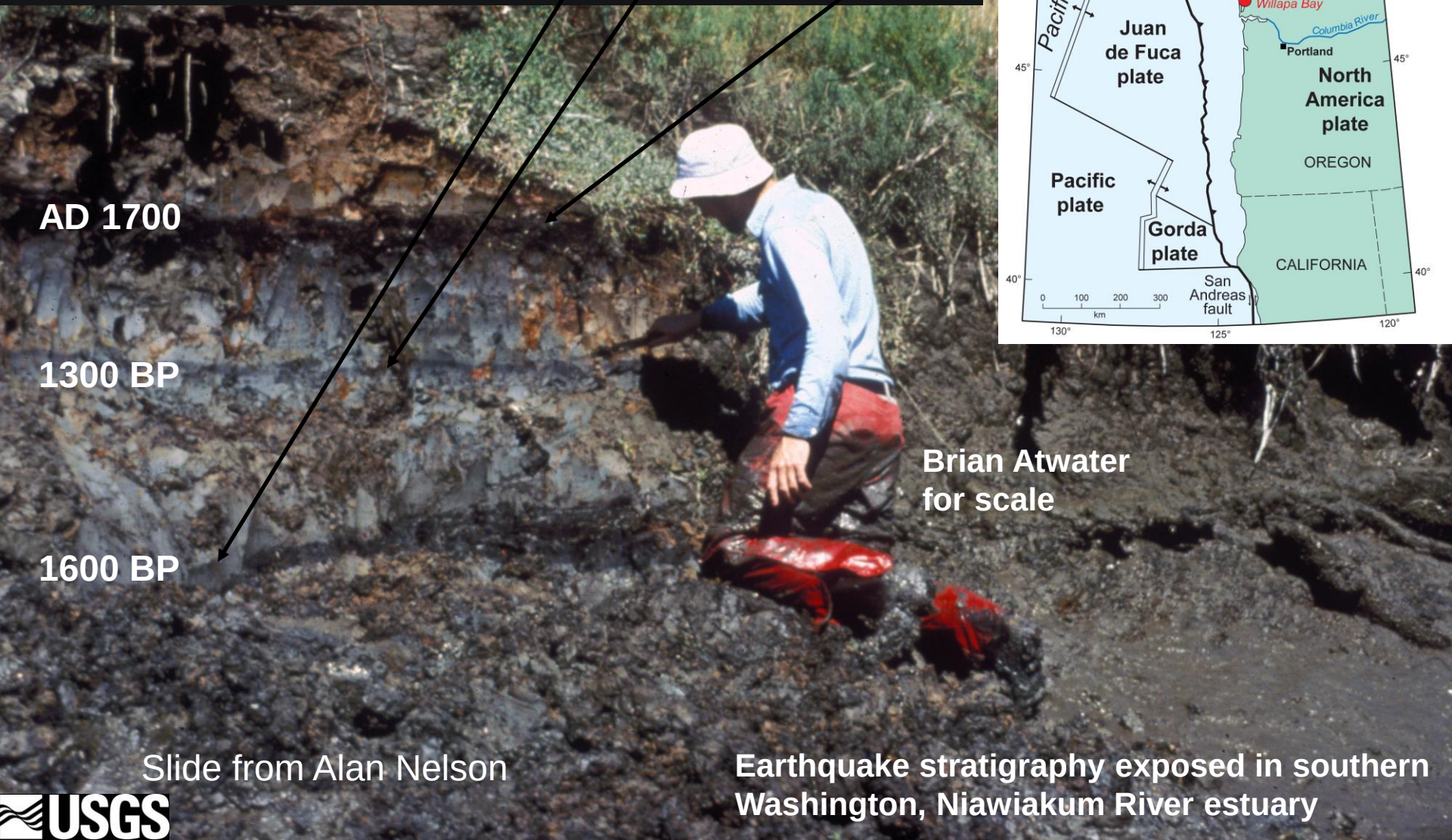

Slide from Alan Nelson

Earthquake stratigraphy exposed in southern Washington, Niawiakum River estuary

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Annu. Rev. Marine. Sci. 2011.3:35-66. Downloaded from www.annualreviews.org
by Oregon State University on 01/14/11. For personal use only.

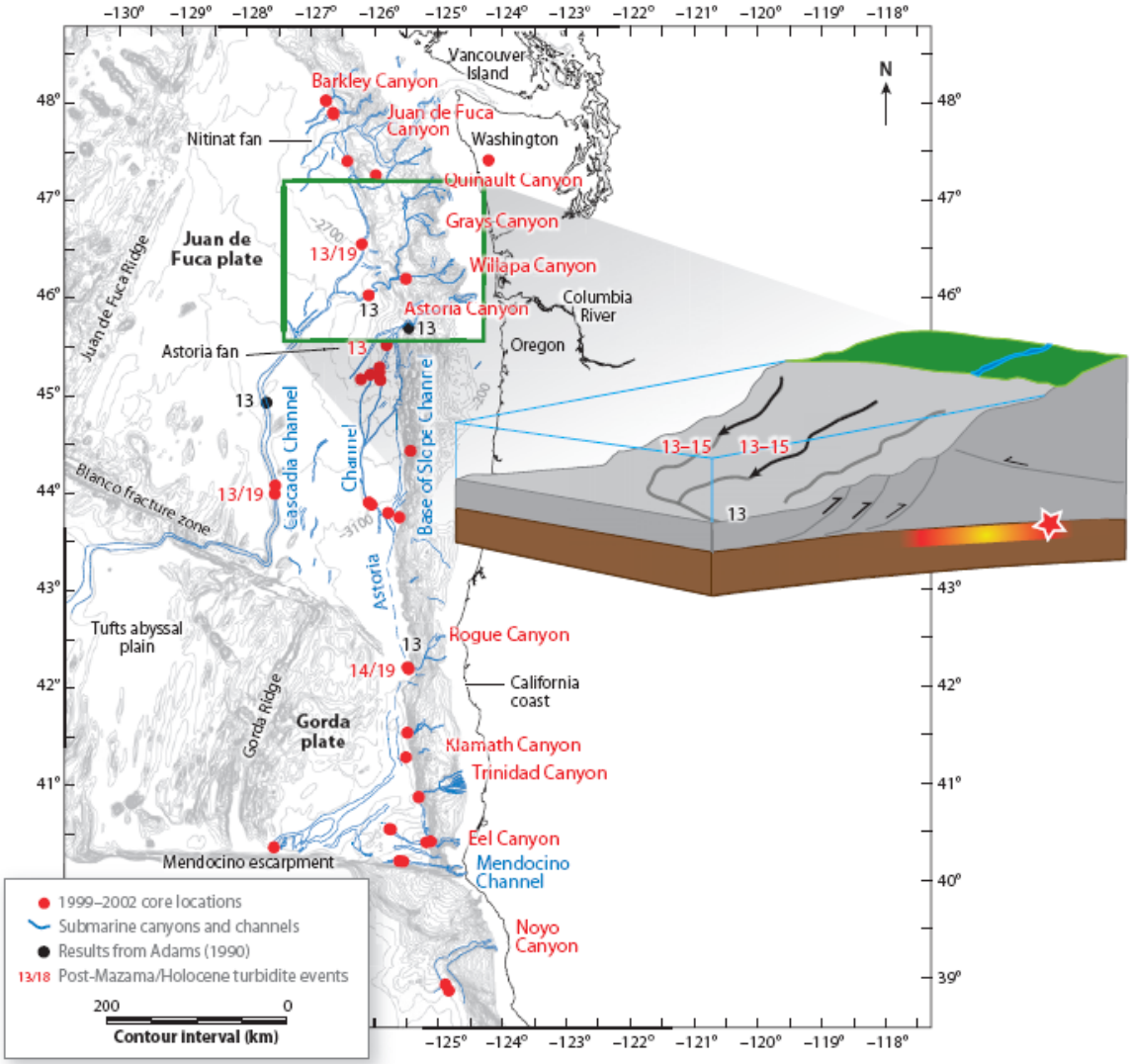


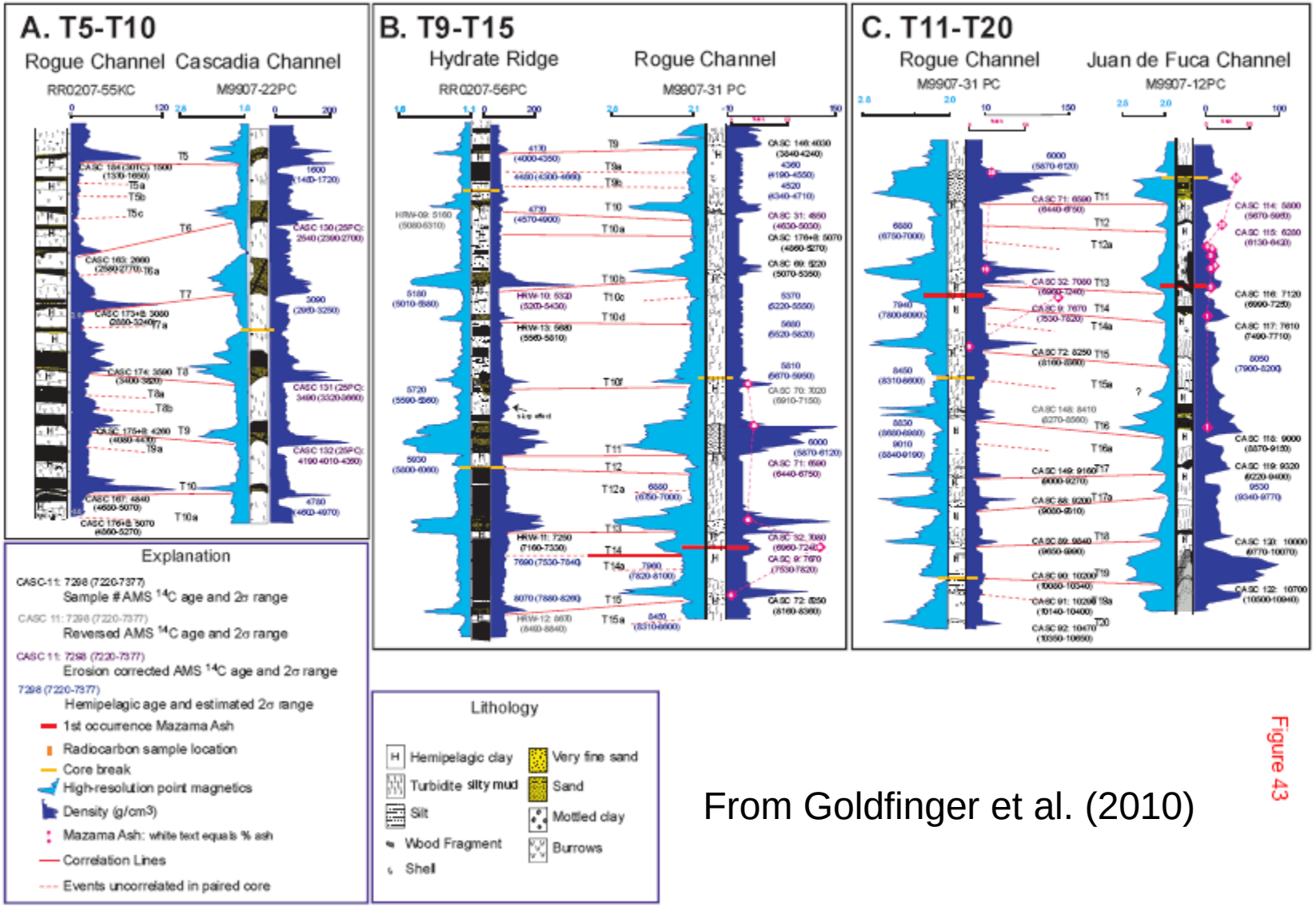
Figure 6

Synchroneity test at a channel confluence as applied where multiple Washington channels merge into the Cascadia Deep Sea Channel (*green square*). The number of events downstream should be the sum of events in the tributaries, unless the turbidity currents were triggered simultaneously. The remarkable similarity of records in northern Cascadia supports the initial conclusion of Adams (1990) that these events are likely of earthquake origin. The number of events present above the Mazama ash remains constant between tributaries and the main stem. The internal structure and number of coarse pulses also remain constant after passage through the confluence.

Figure from Goldfinger (2010)

Turbidite channels
And locations of cores

CORRELATION EXAMPLES



From Goldfinger et al. (2010)

Figure 43

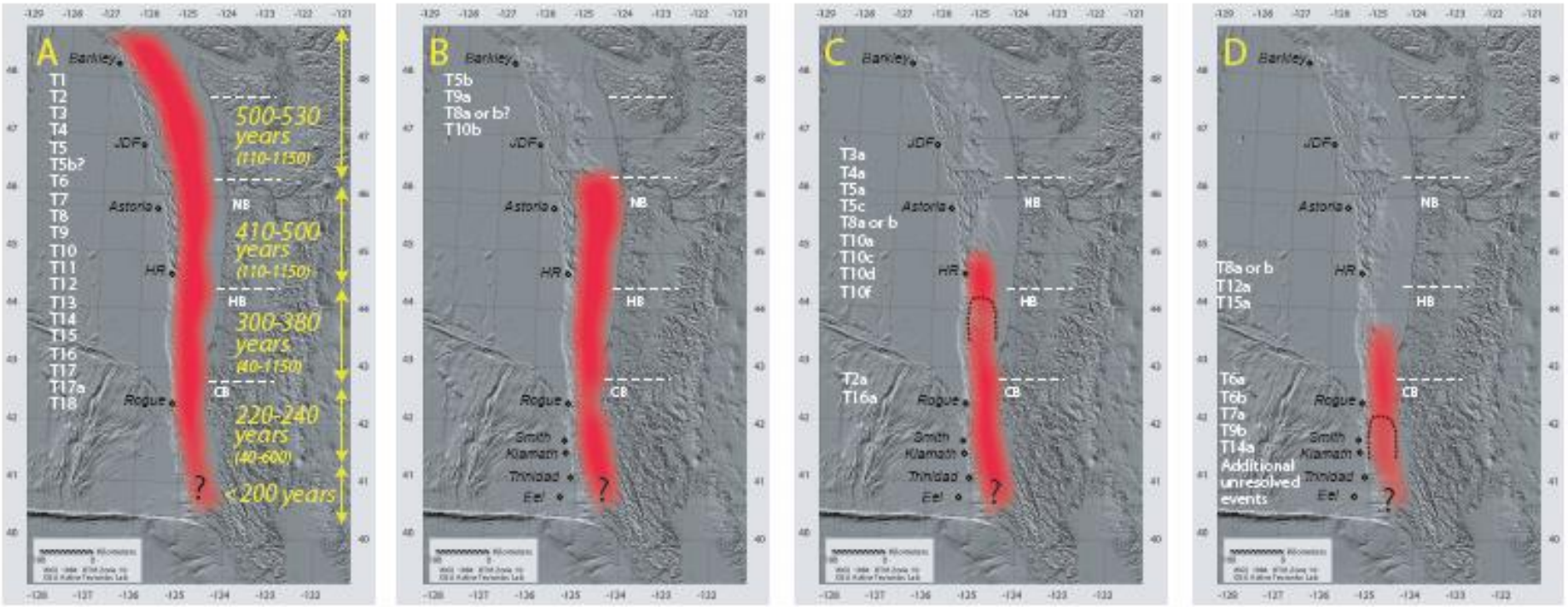
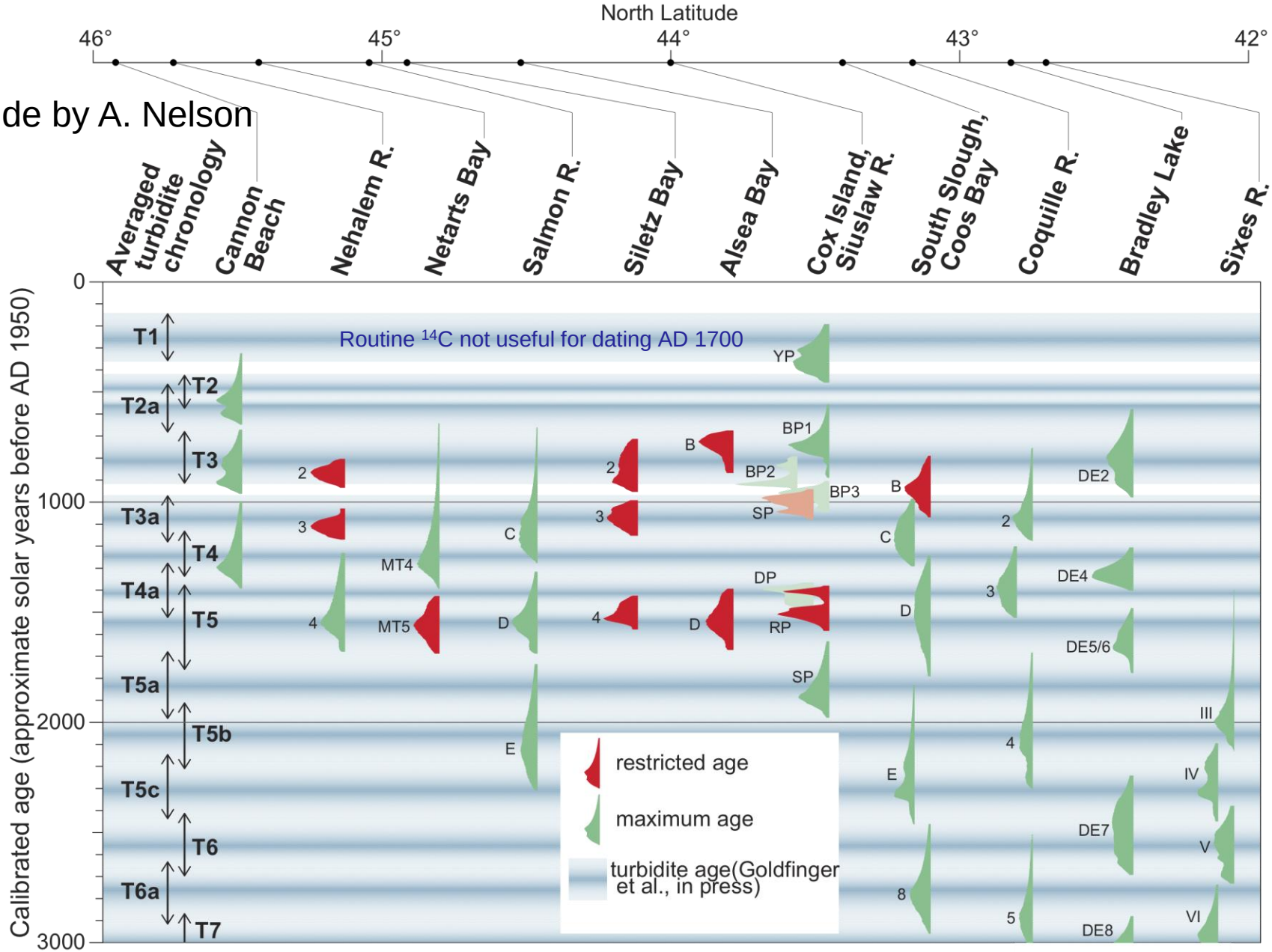


Figure from Goldfinger et al. (2012); great earthquake ruptures inferred from turbidites over past 10,000 years

We convened workshop at Oregon State University on Nov 18-19, 2010 to evaluate turbidite data for constraining recurrence models for CSZ

See Frankel (2011) USGS Open-File Report 2011-1310 for summary

Slide by A. Nelson



Overlaps on radiocarbon age distributions are merely consistent with correlations of subsidence stratigraphy from site to site

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workshop consensus on southern CSZ

- About 10 partial CSZ rupture events in past 10,000 years (half of number in Goldfinger et al., 2012). Some workshop participants skeptical of correlations of gravity and magnetic logs from widely-spaced cores. However, most thought the rough correspondence of rates between turbidites and on shore data (Bradley Lake, Sixes River) was indicative of M8+ earthquakes that ruptured only the southern CSZ
- Implies recurrence time of about 340 years in southern CSZ for earthquakes of M8 or larger (including M9 events with average recurrence time of 500 yr)
- Note that we already had M8.0-8.7 partial CSZ rupture events in 2008 model, but they are distributed along whole zone)
- Not clear if there are M8 partial CSZ ruptures in northern portion of CSZ; may be difficult to identify in turbidites and onshore data

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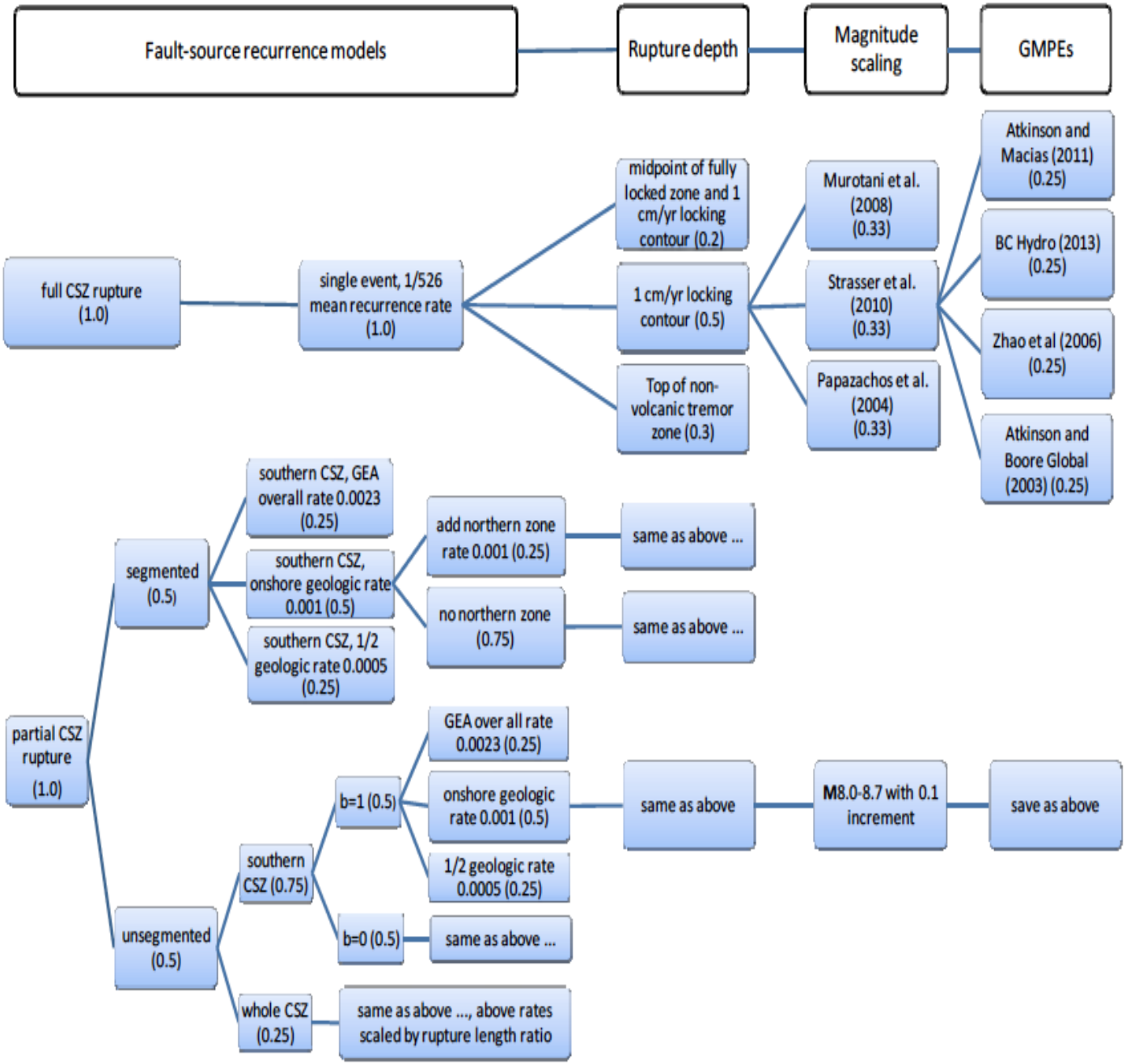
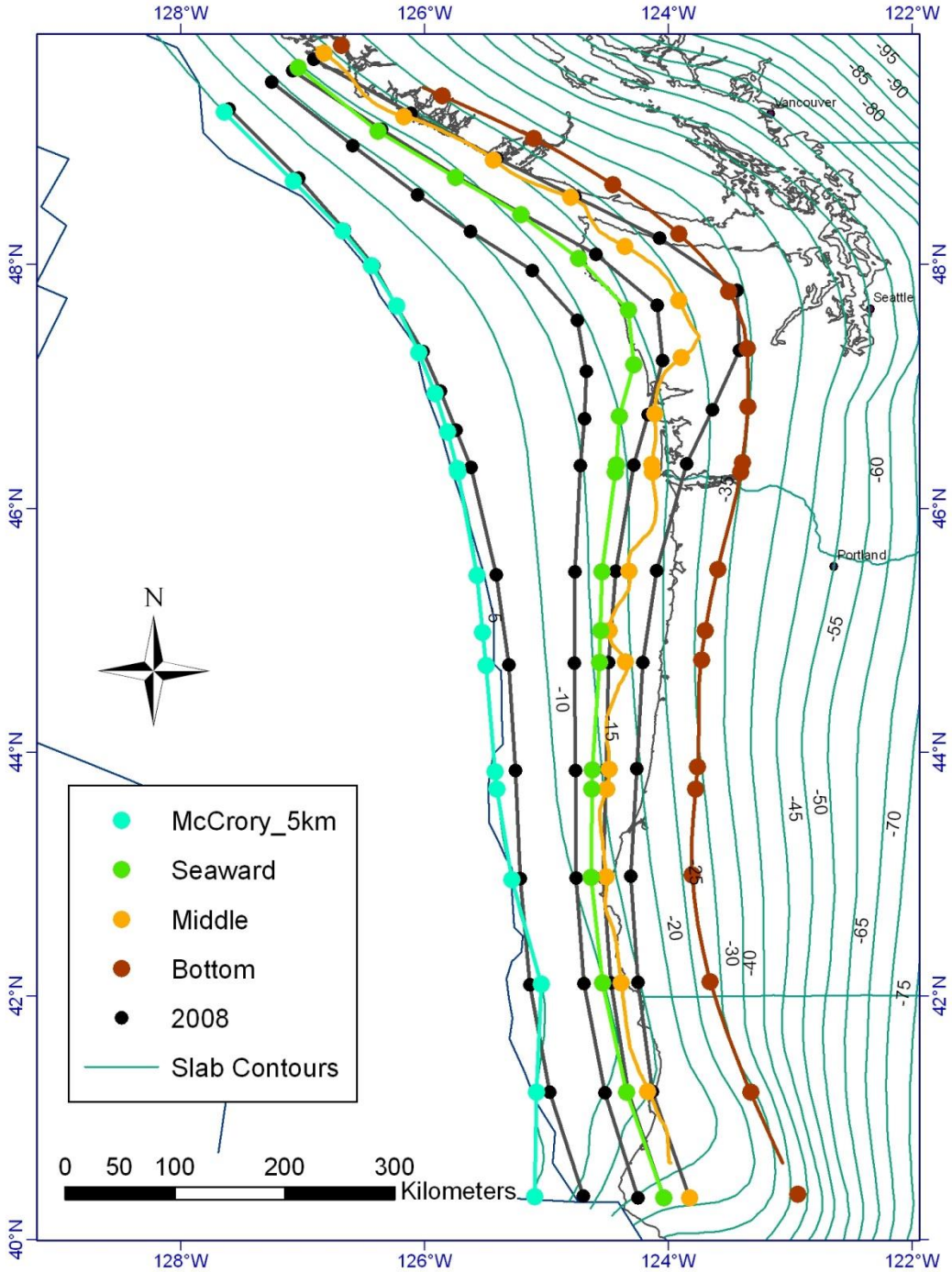


Logic trees for Cascadia earthquakes used in 2014 maps

Slide from Rui Chen (CGS)



Green, orange, and red lines are models of eastern edge of CSZ ruptures used in 2014 NSHM's

Orange: 1 cm/yr locking averaged from geodetic studies of McCaffrey; Schmidt

Red: is top of tremor zone (from Wech) associated with slow slip events

Green: midpoint of thernal modeling and geodetic

Slide from Rui Chen, CGS

Ground-motion prediction equations (GMPE's) used for interface earthquakes (based on fitting data from various subduction zones)

- Zhao et al. (2006) 0.25 wt
- BC Hydro (Addo et al., 2012), 0.25 wt
- Atkinson and Macias (2011). 0.25 wt (used finite-fault stochastic modeling)
- Atkinson and Boore (2003), global 0.25wt

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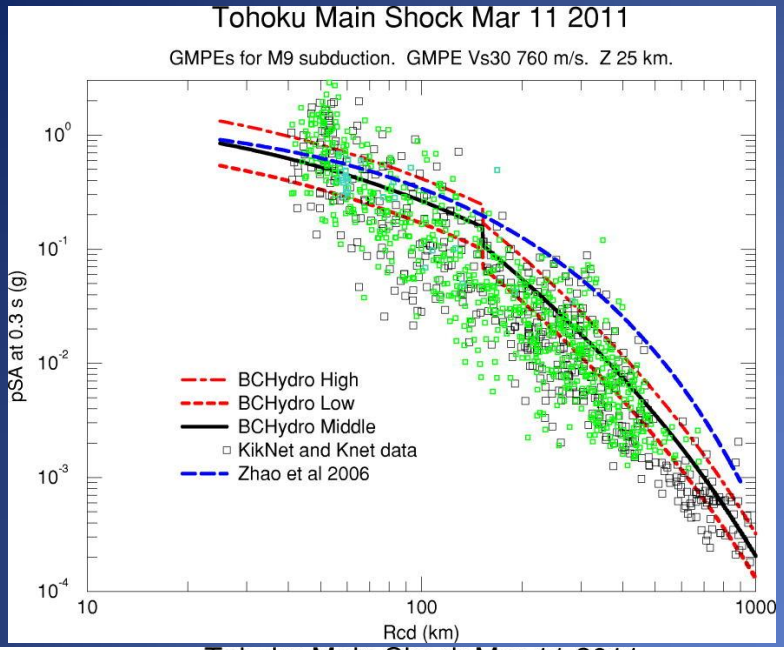
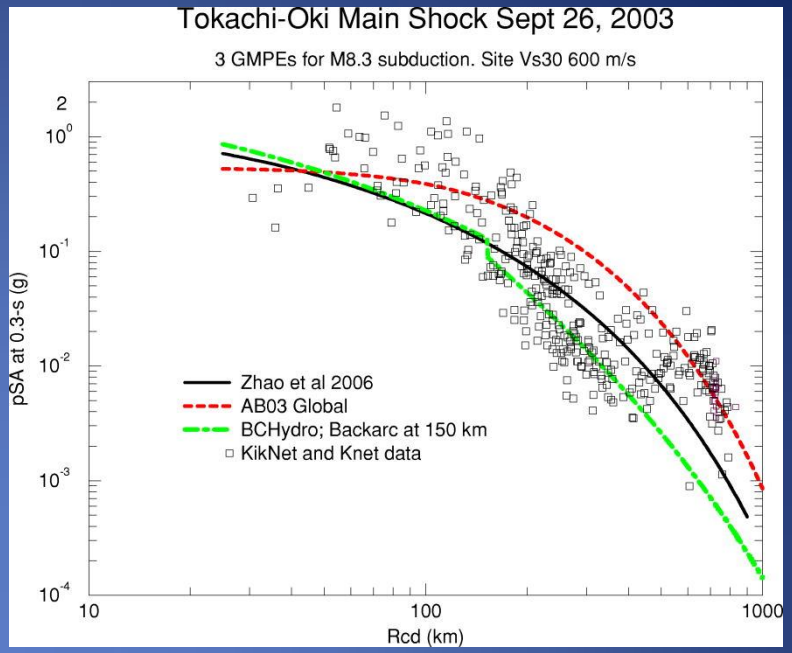
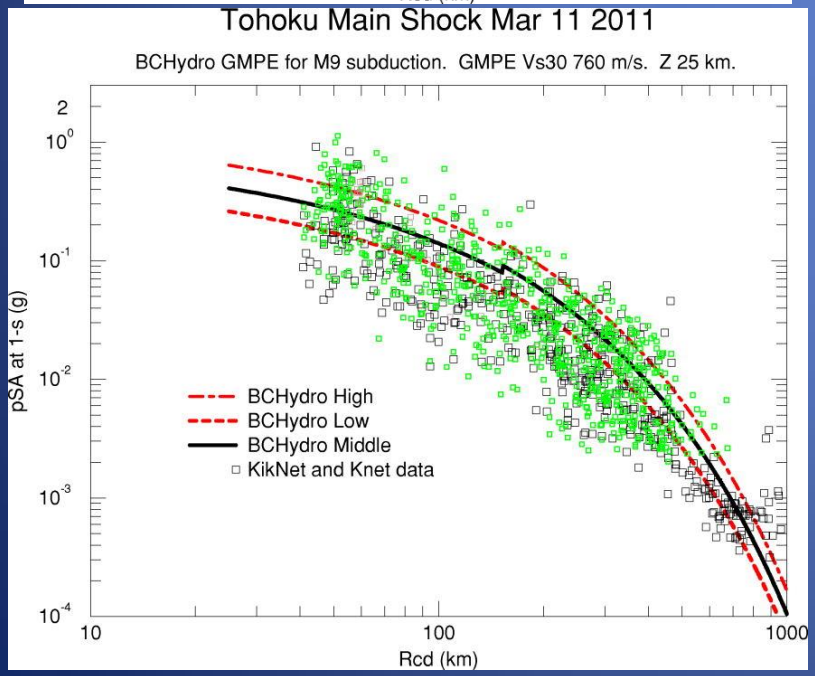

Tohoku Main Shock Mar 11 2011
GMPEs for M9 subduction. GMPE Vs30 760 m/s. Z 25 km.
pSA at 0.3 s (g)
Rcd (km)
BCHydro High
BCHydro Low
BCHydro Middle
KikNet and Knet data
Zhao et al 2006


Tokachi-Oki Main Shock Sept 26, 2003
3 GMPEs for M8.3 subduction. Site Vs30 600 m/s
pSA at 0.3-s (g)
Rcd (km)
Zhao et al 2006
AB03 Global
BCHydro; Backarc at 150 km
KikNet and Knet data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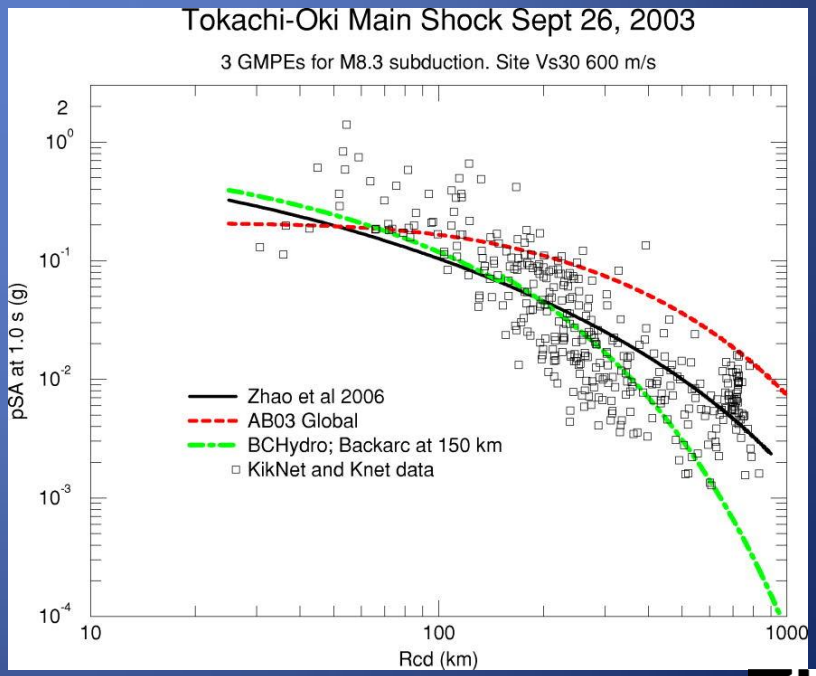
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Rcd (km)
Zhao et al 2006
AB03 Global
BCHydro; Backarc at 150 km
KikNet and Knet data

Ground-motion Prediction Equations for Other Sources

- For crustal faults and seismicity, we used NGA West 2 GMPE's (from 5 developers)
- For deep (> 35 km) intraslab earthquakes, we used:

Zhao et al. (2006) 0.33 wt

BC Hydro (2012) 0.33 wt

Atkinson and Boore (2003) global 0.17 wt

Atkinson and Boore (2003) Cascadia 0.17 wt

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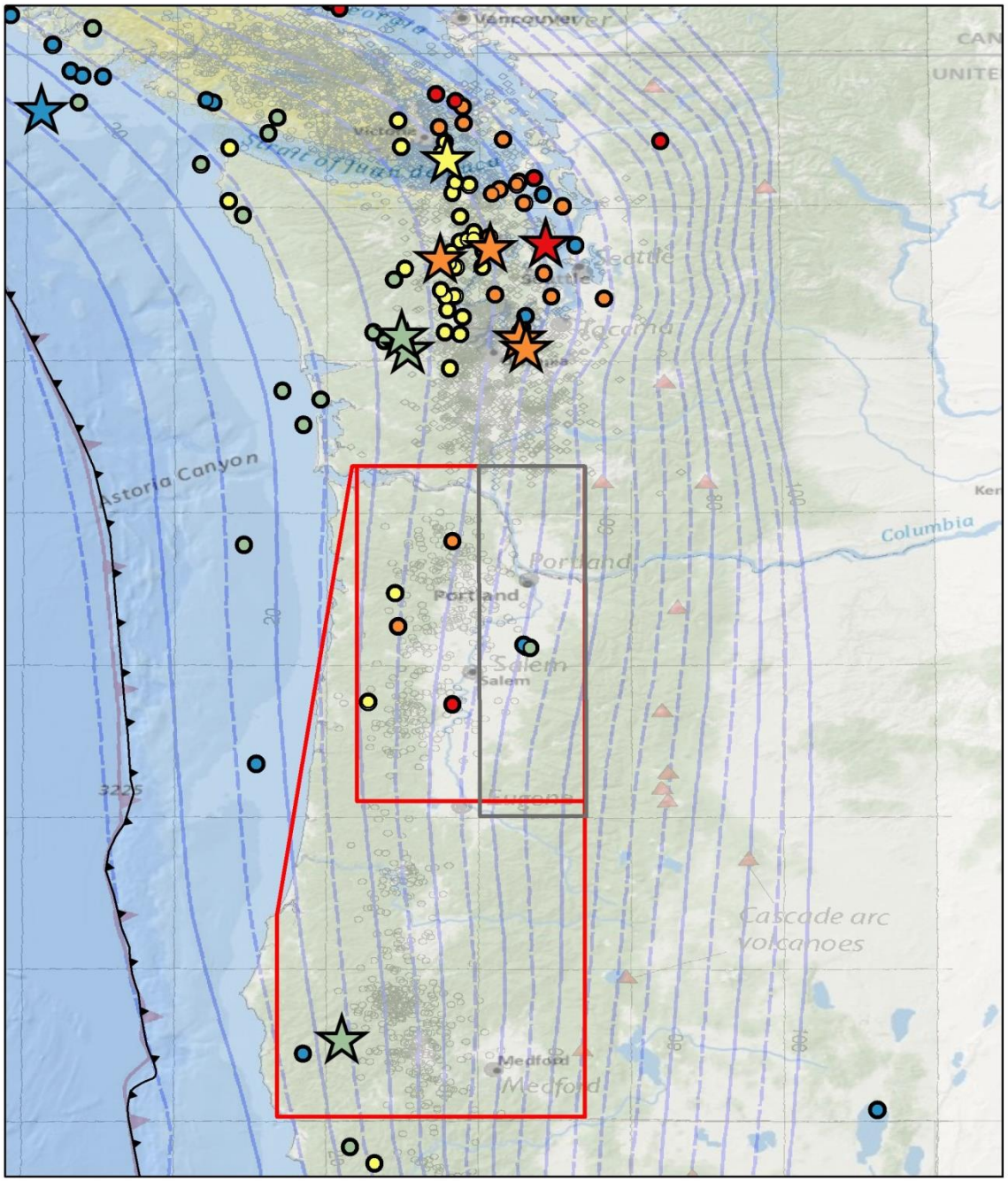
New coastal deep zone (replaces Portland zone)



- Rate determined from earthquakes that are beneath the subduction interface; 7 M>=2.5 since 1990, 6 events in red zone
- Accounts for deep earthquakes where few M>=4 earthquakes have occurred

Slide from Morgan Moschetti

depth

- 30 - 34
- 35 - 40
- 41 - 48
- 49 - 57
- 58 - 71

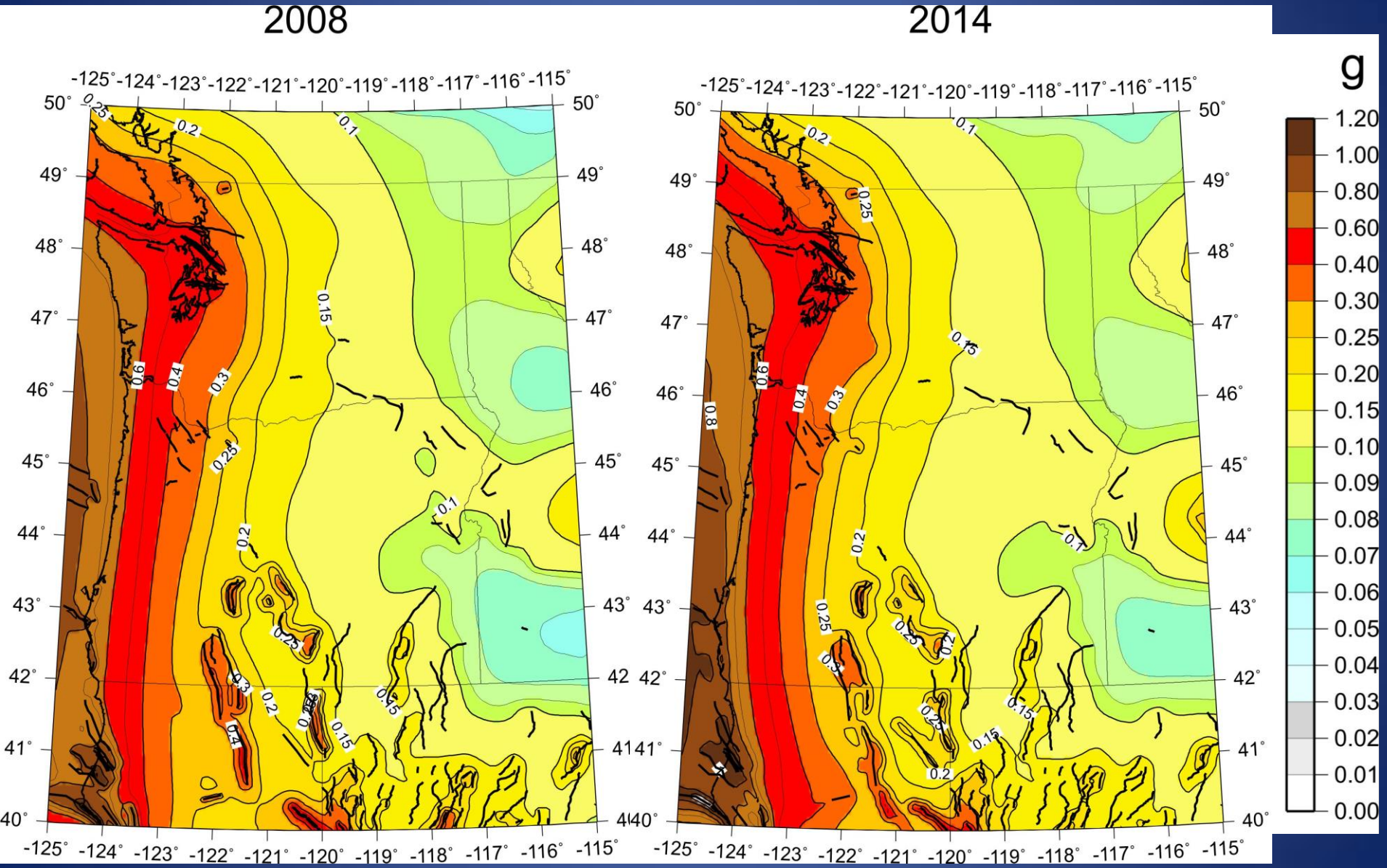
mag

- < 4.0
- 4.0 - 6.8

Portland Zone

New Portland Zone

1.0 second Spectral Acceleration with 2% Probability of Exceedance in 50 Years



USGS web tools for seismic-hazard and fault information

- National seismic hazard maps: earthquake.usgs.gov/hazards
- Quaternary fault and fold database (interactive; with KML and GIS shapefiles of fault traces) earthquake.usgs.gov/hazards/qfaults
- Fault database used in NSHM (uses simplified fault traces and faults with measured slip rates and/or recurrence); see "Fault Data Used in the Hazard Maps" link in qfaults. You can look up slip rates, recurrence rates, etc. used in NSHM

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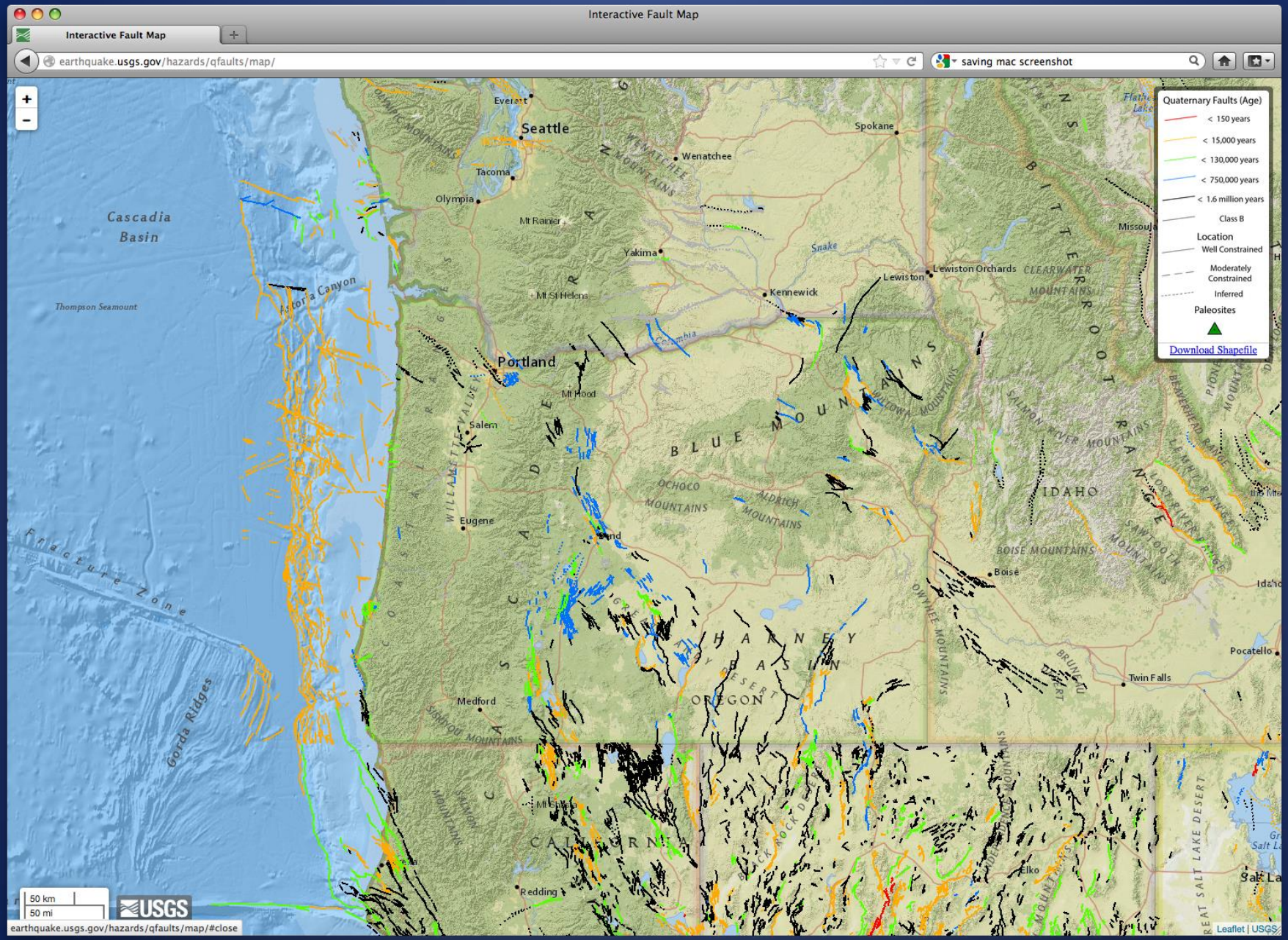
Quaternary Fault Database



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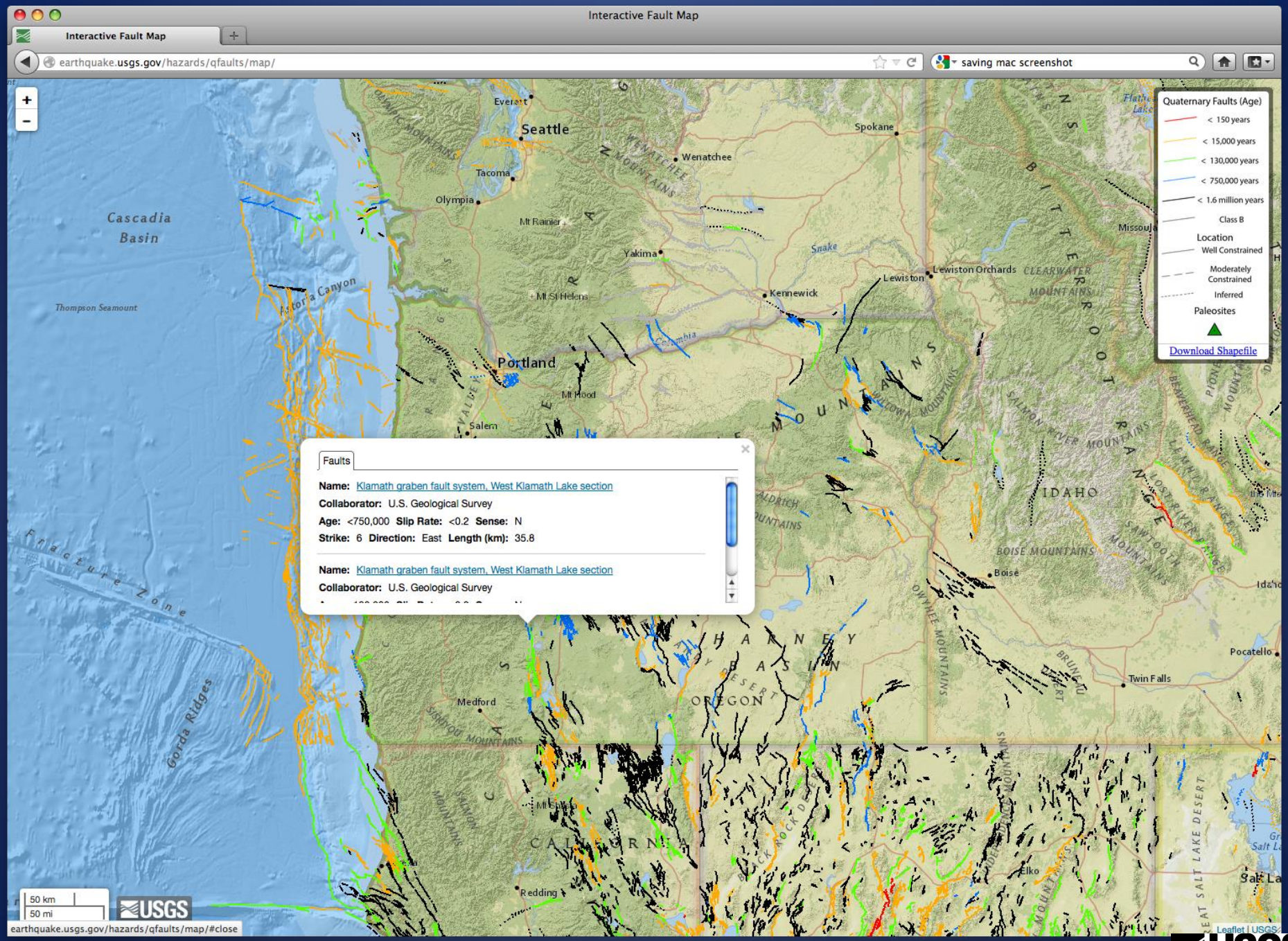

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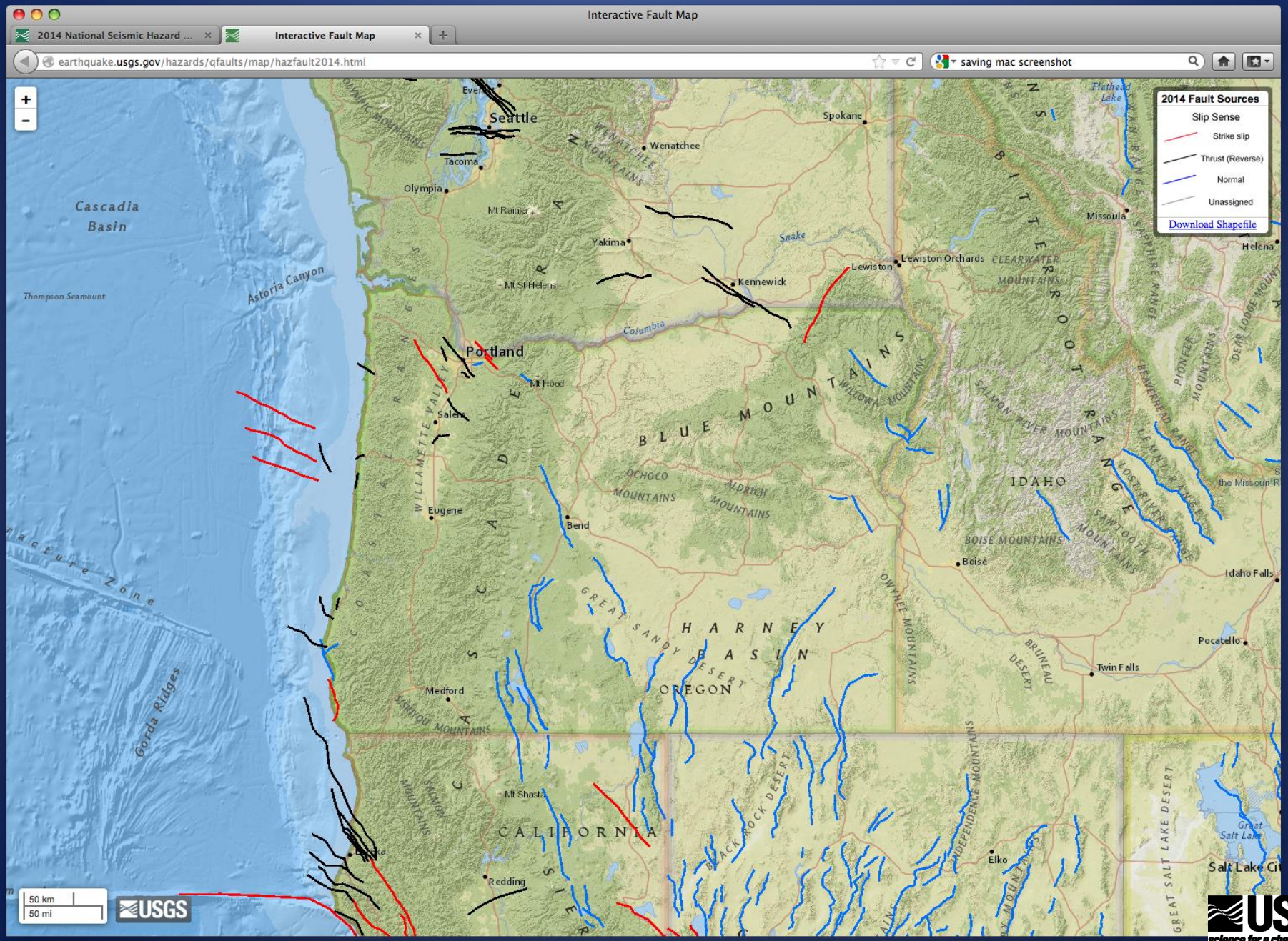
Faults used in National Seismic Hazard Maps



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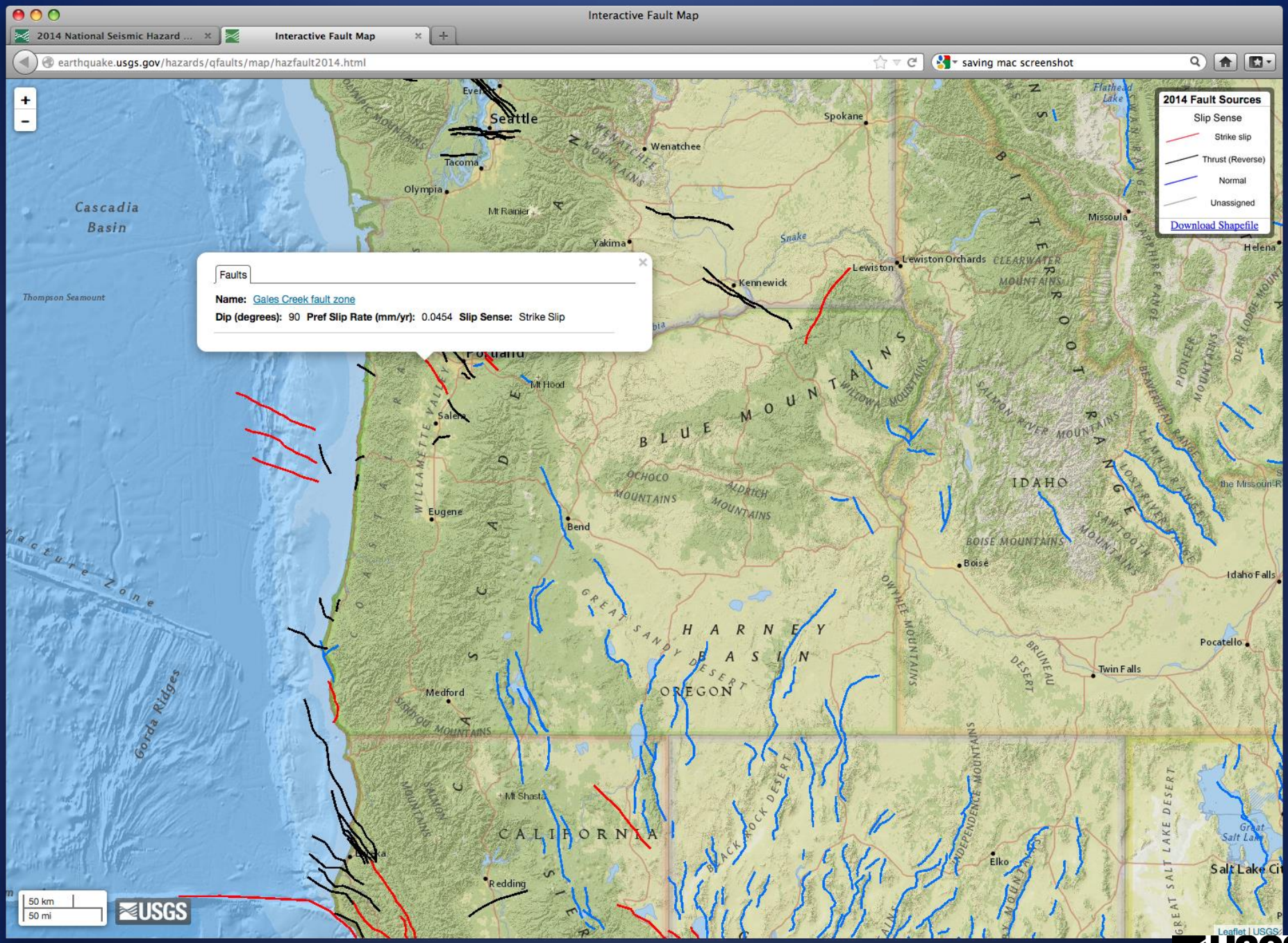

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More USGS web tools for seismic-hazard information in earthquake.usgs.gov/hazards/

- Hazard curves and uniform hazard spectra at selected latitude, longitude
- Deaggregations at selected lat, lon, period, probability of exceedance, and site class
- Seismic design values (IBC, ASCE 7, AASHTO Bridge); risk targeted values

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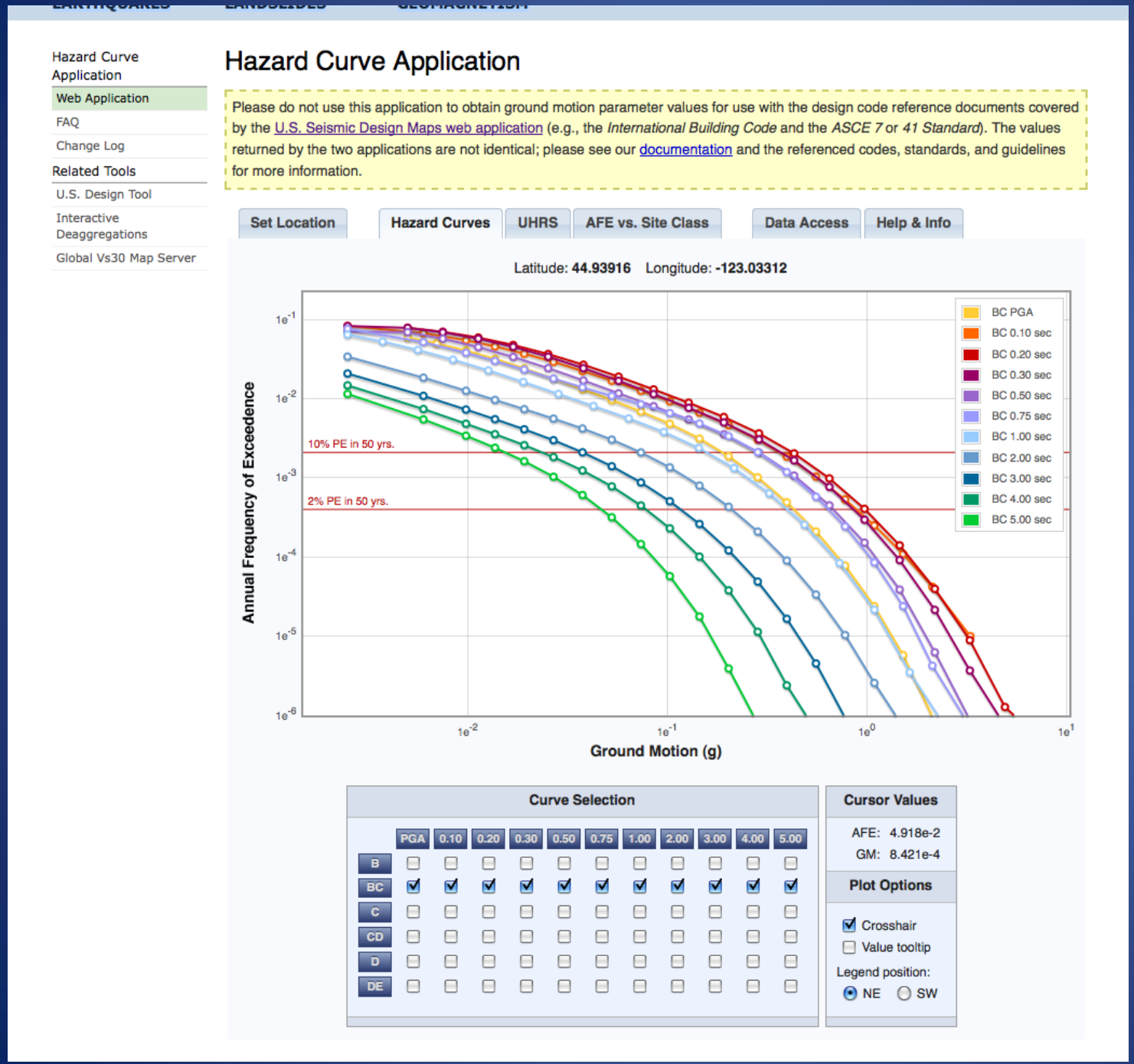
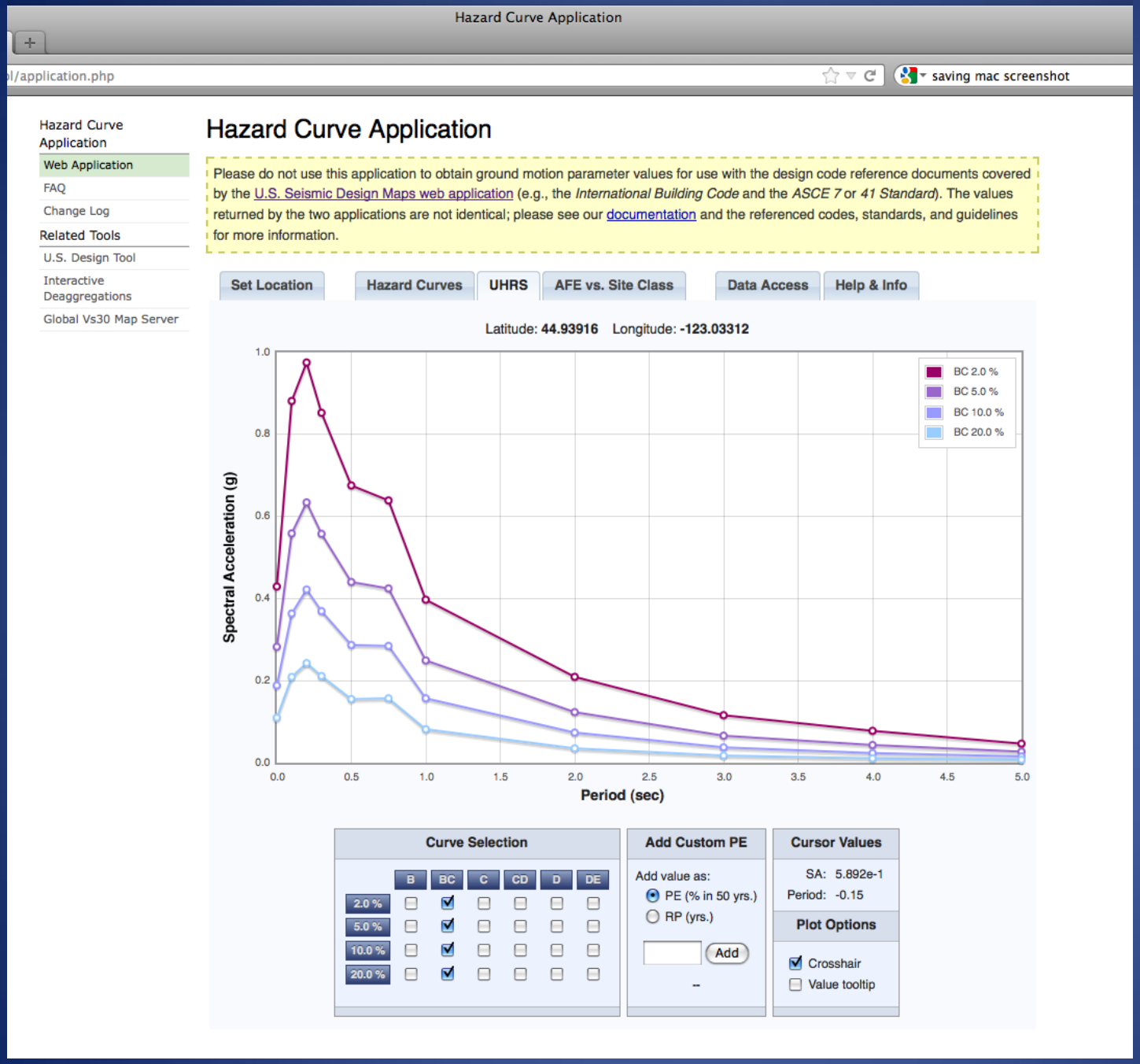


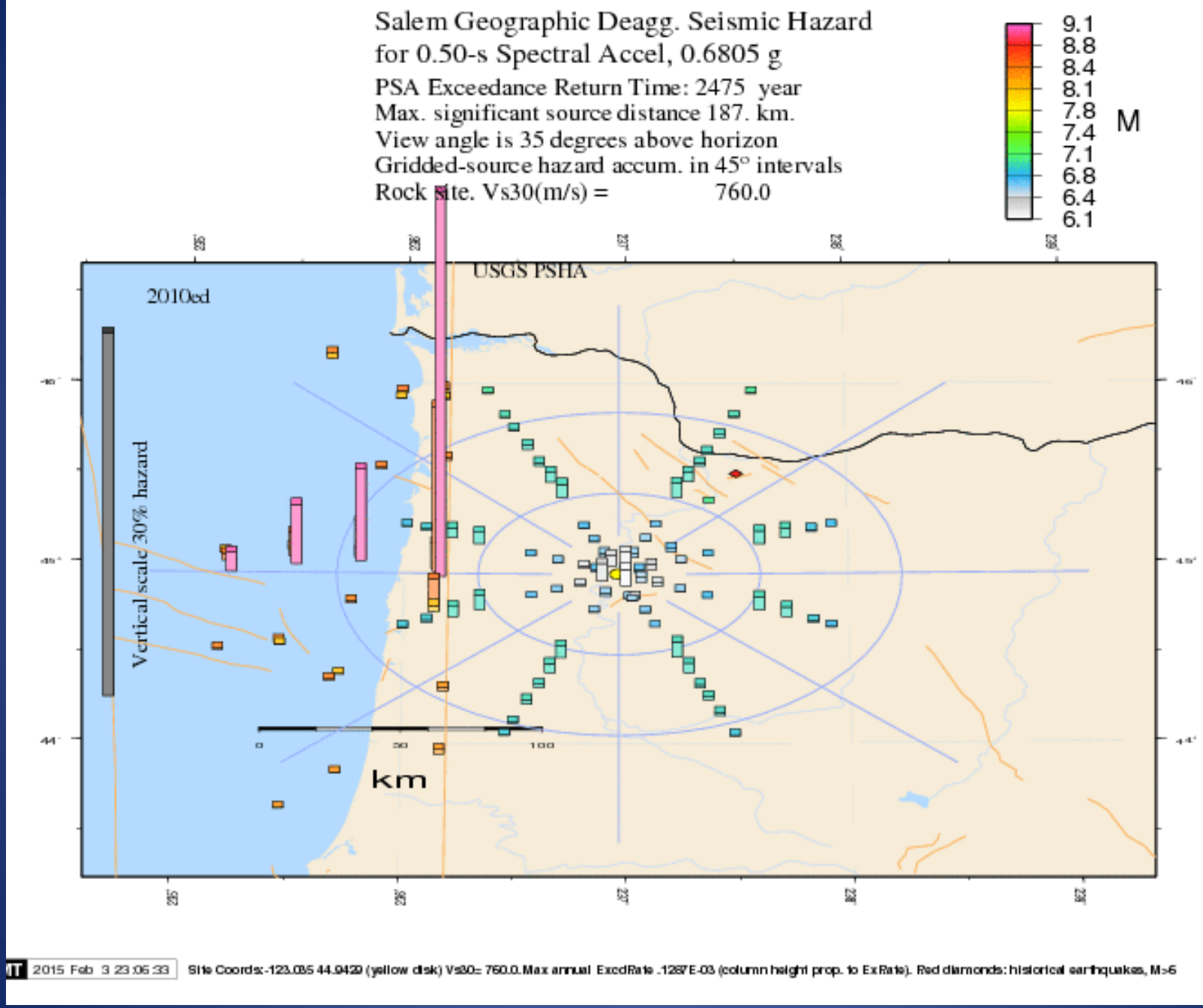
Ground-motion values for annual probabilities less than 10^{-4} should be used with caution. The NSHM only uses faults with measured slip rates or recurrence.

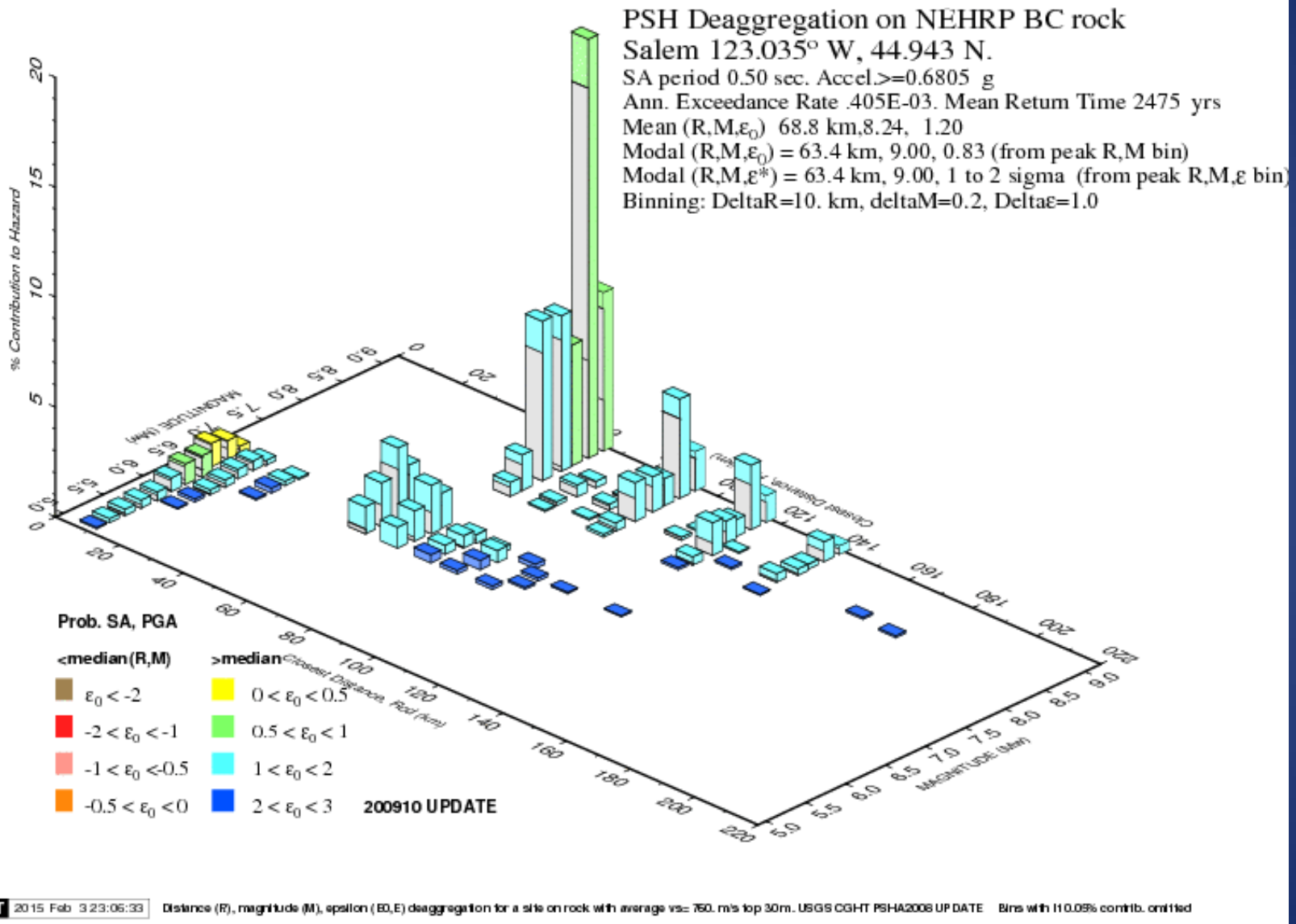
Based on 2008 Values; will be updated with 2014 values



Uniform Hazard Spectra

(2008 values; will be updated with 2014 values)


Salem Geographic Deagg. Seismic Hazard
for 0.50-s Spectral Accel, 0.6805 g
PSA Exceedance Return Time: 2475 year
Max. significant source distance 187. km.
View angle is 35 degrees above horizon
Gridded-source hazard accum. in 45° intervals
Rock site. Vs30(m/s) = 760.0
9.1
8.8
8.4
8.1
7.8
7.4
7.1
6.8
6.4
6.1
M
USGS PSHA
2010ed
Vertical scale 30% hazard
km
0
50
100
2015 Feb 3 23:06:33
Site Coords:-123.035 44.9429 (yellow disk) Vs30= 760.0. Max annual ExceedRate .1287E-03 (column height prop. to ExRate). Red diamonds: historical earthquakes, M>6



Text file gives information on contributions to hazard from specific faults

Where to get subduction-zone strong-motion recordings

- For M9.0 Tohoku, Japan and M8.8 Maule, Chile earthquakes: Center for Engineering Strong-Motion Data (run by CGS, USGS, data from NIED, Univ. of Chile; see "archive"): strongmotioncenter.org

also NIED Japan for K-Net and KiK-net data: www.kyoshin.bosai.go.jp

- Also COSMOS virtual data center for older data (including Nisqually EQ): strongmotioncenter.org/vdc/scripts/default.plx
- PEER NGA-subduction zone is starting (Yousef Bozorgnia, PEER) to collect global records

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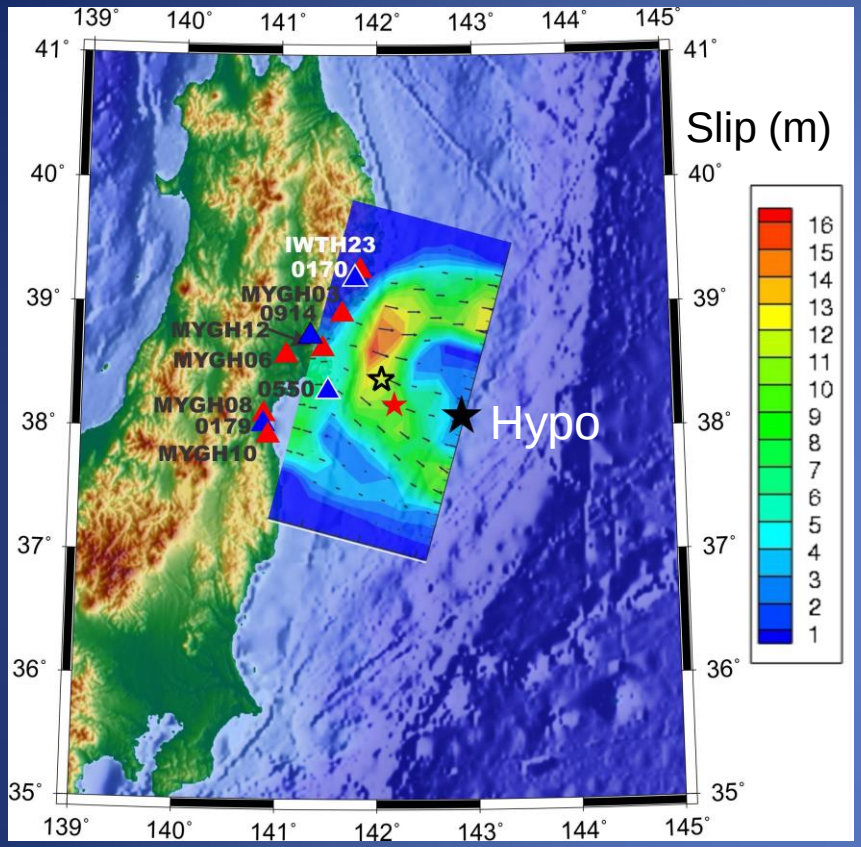
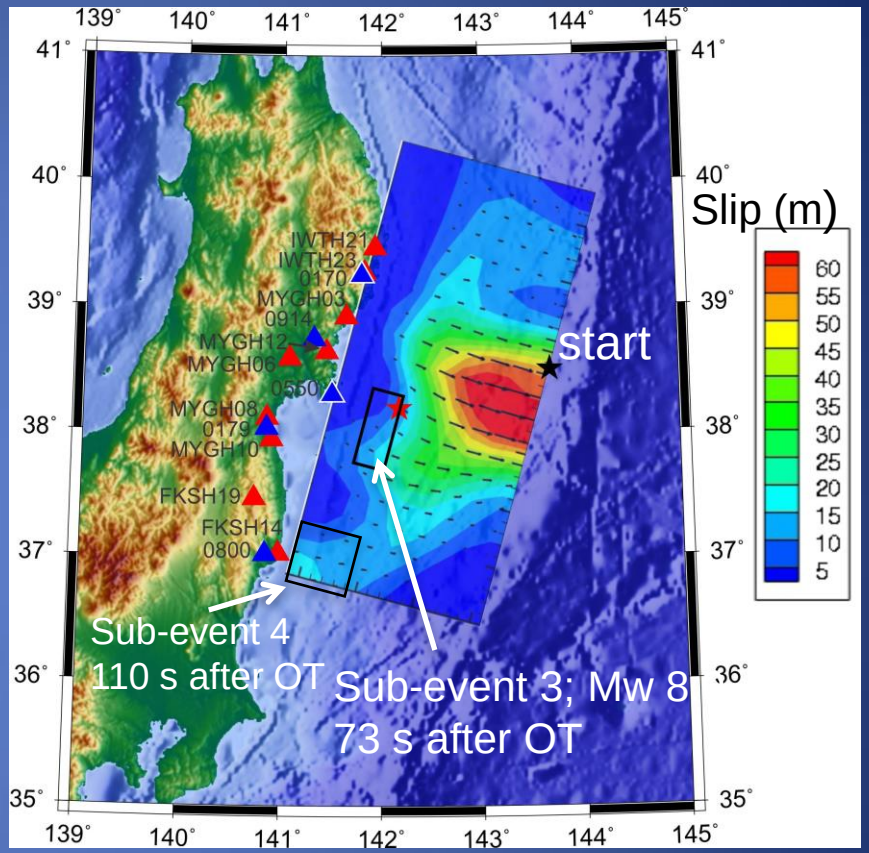
Tohoku earthquake: Results of inversions of velocity waveforms from strong-motion records (0-0.2 Hz) and 1 sps GPS displacement waveforms (Frankel, 2013)

Sub-event 1; Mw 8.5



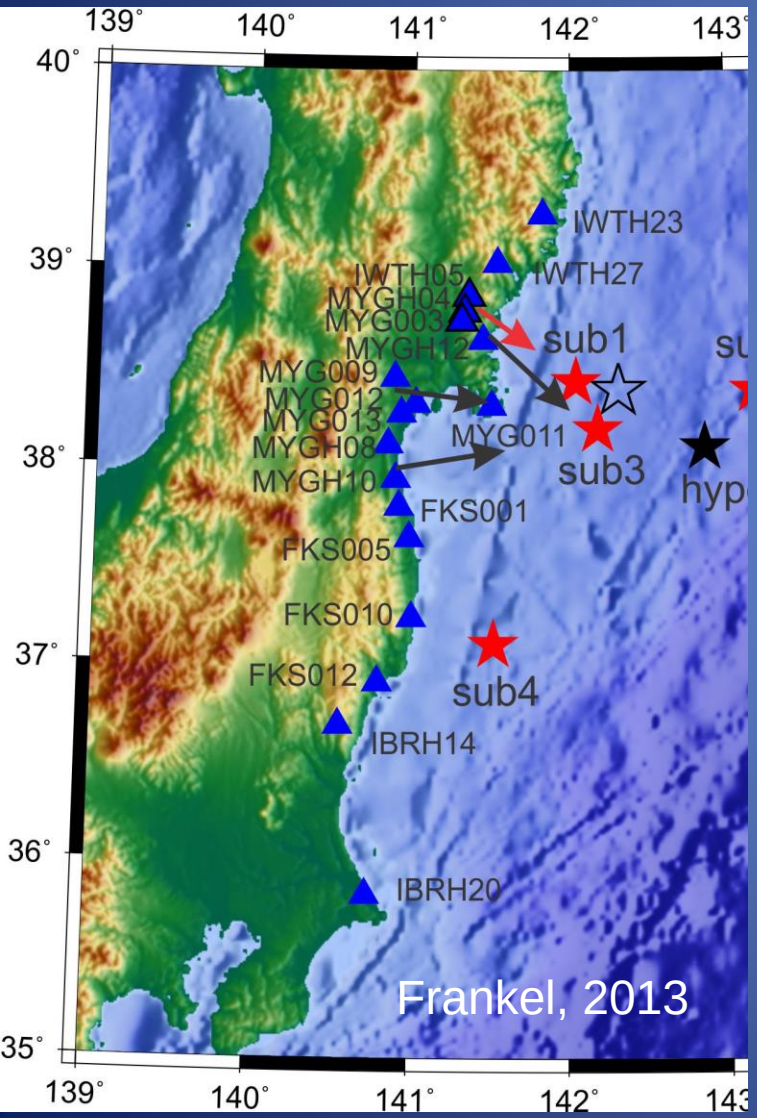
Sub-event 2; Mw 9.0, starts 35 s later



Sub-event 1 ruptures downdip and to north; generates low (< 0.2 Hz) and high frequency ground motions

As sub-event 2 ruptures down dip and to south, high-frequency sub-events 3 and 4 occur (d=40 km). Sub-event 2 only generates low frequencies (< 0.2 Hz) at shallow depths (< 30 km), has rise time of slip of about 40 sec.

For frequencies of engineering interest, 0.1 to 20 Hz, the Mw9.0 Tohoku earthquake essentially consists of a series of Mw 8 earthquakes at depths of about 30-40 km with high stress drop



Strong-motion generation areas
From Kurahashi and Irikura (2013)
Based on correlation of
acceleration waveforms at nearby stations

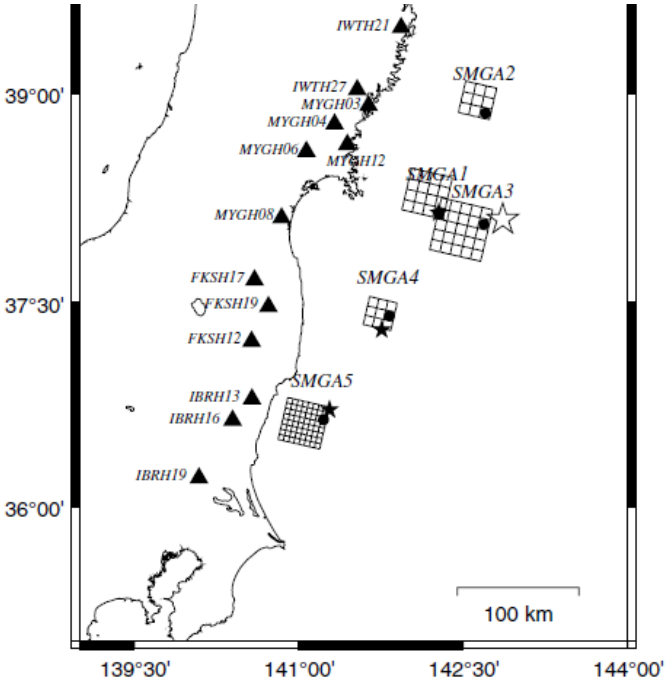
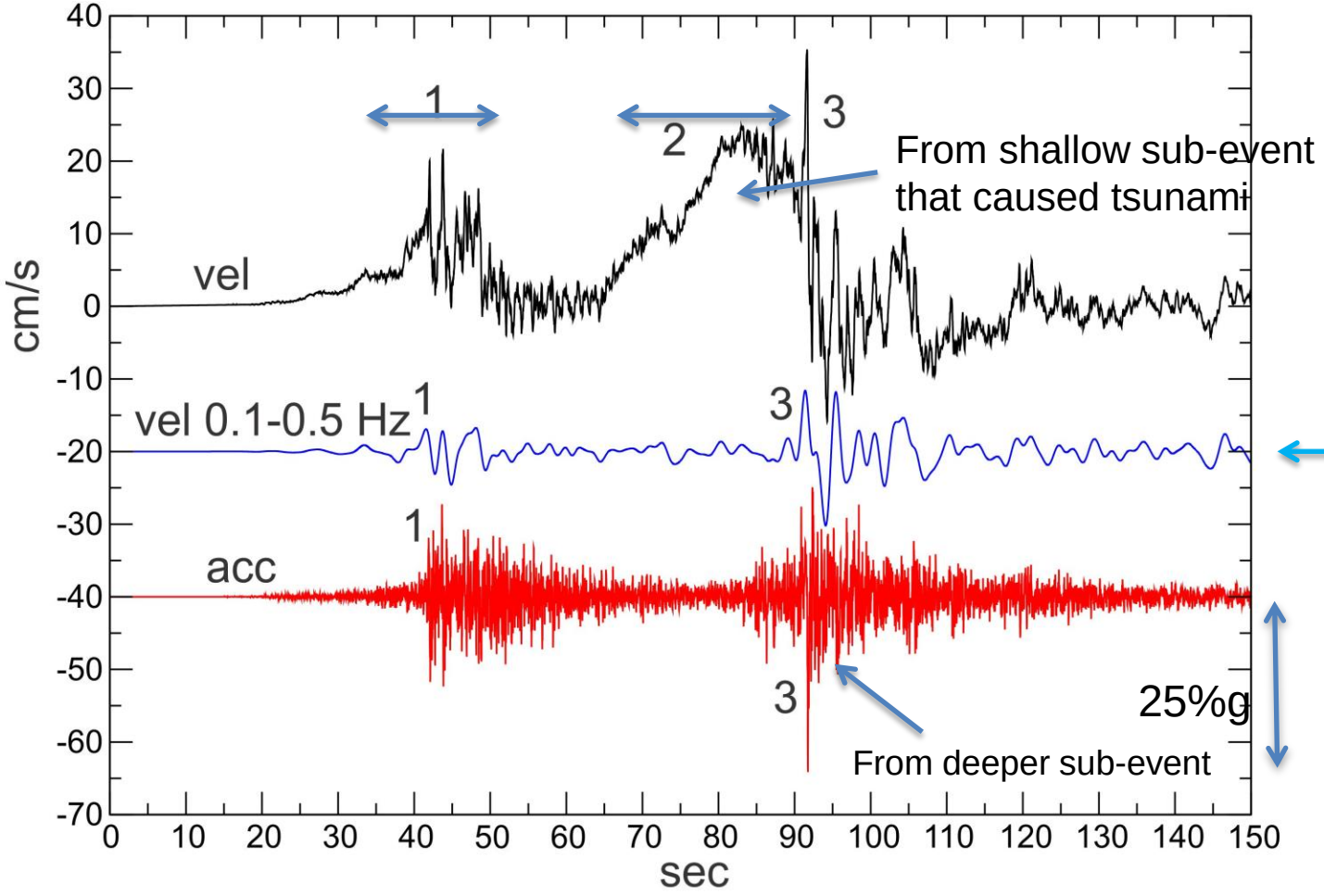


Figure 13. Short-period source model consisting of five strong-motion generation areas (SMGAs; meshed rectangles). The large open star denotes the mainshock epicenter; closed stars, the epicenters of EGF events; and closed circles, the initiation point of each SMGA.

Recording of M9.0 Tohoku, Japan earthquake, station near coast west of hypocenter

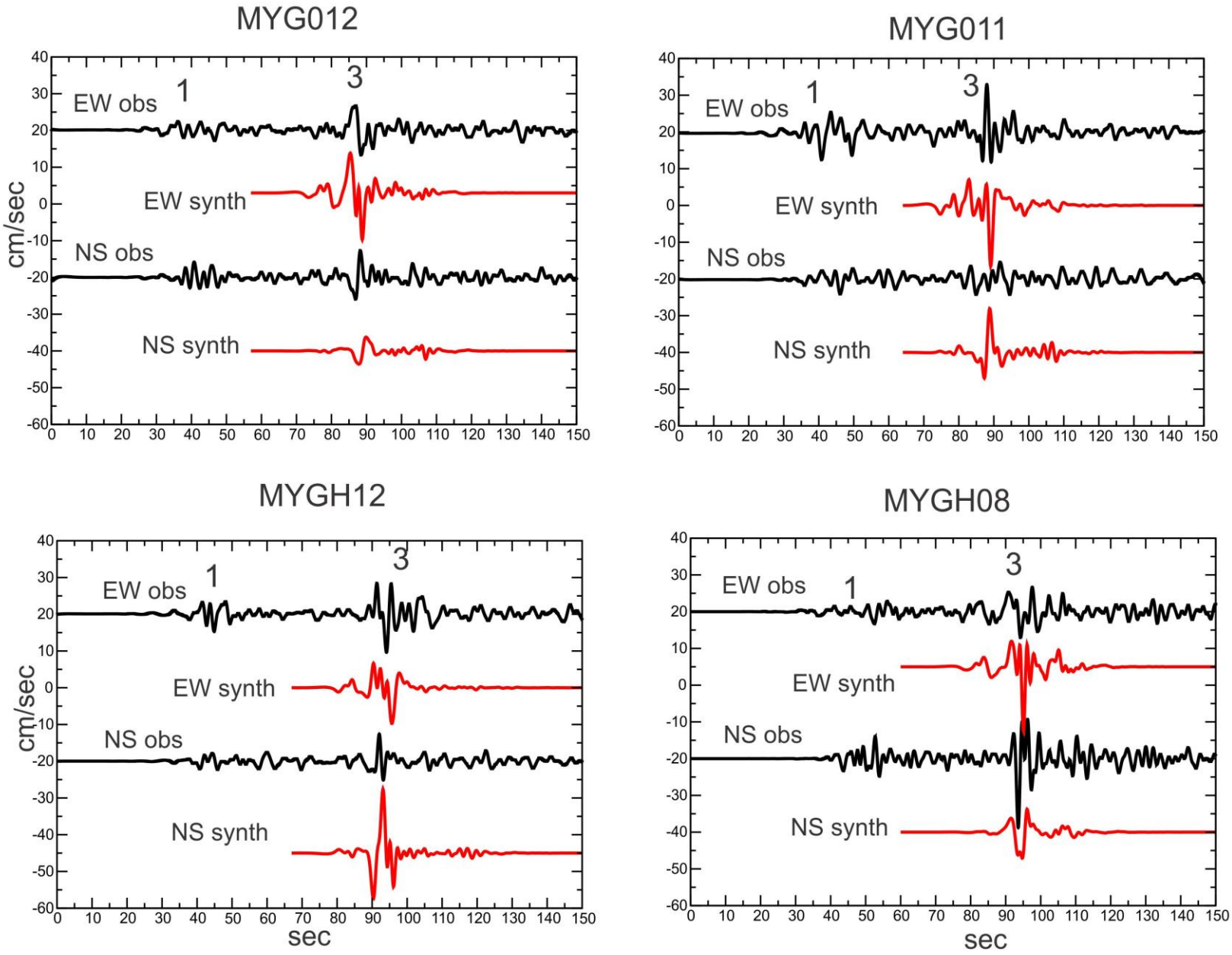
MYGH12 EW

From borehole accel.recording



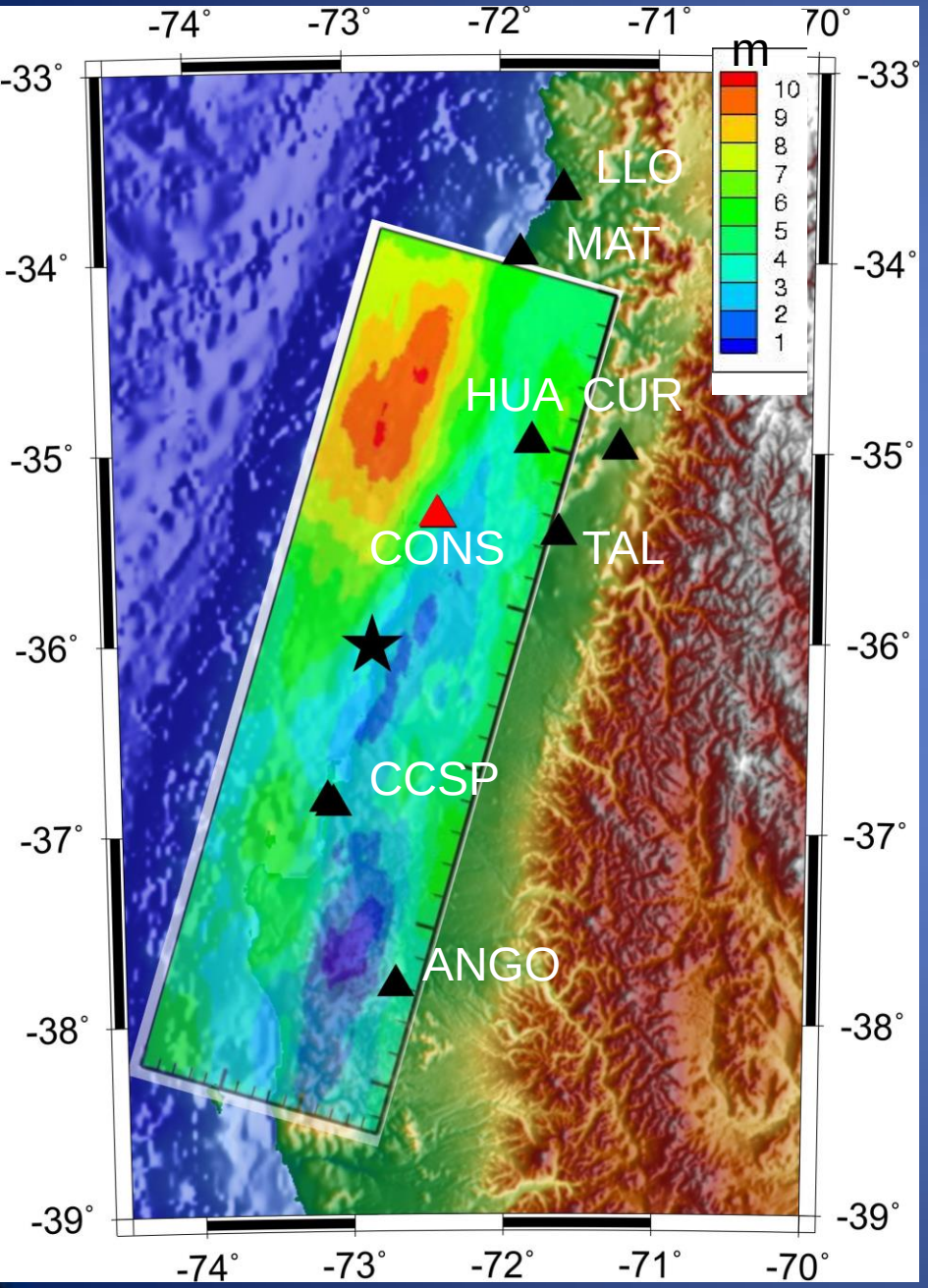
Buildings 20-100 stories are most affected by motions at these frequencies

Synthetics (0.1- 0.5 Hz) based on M8.0 source with high stress drop

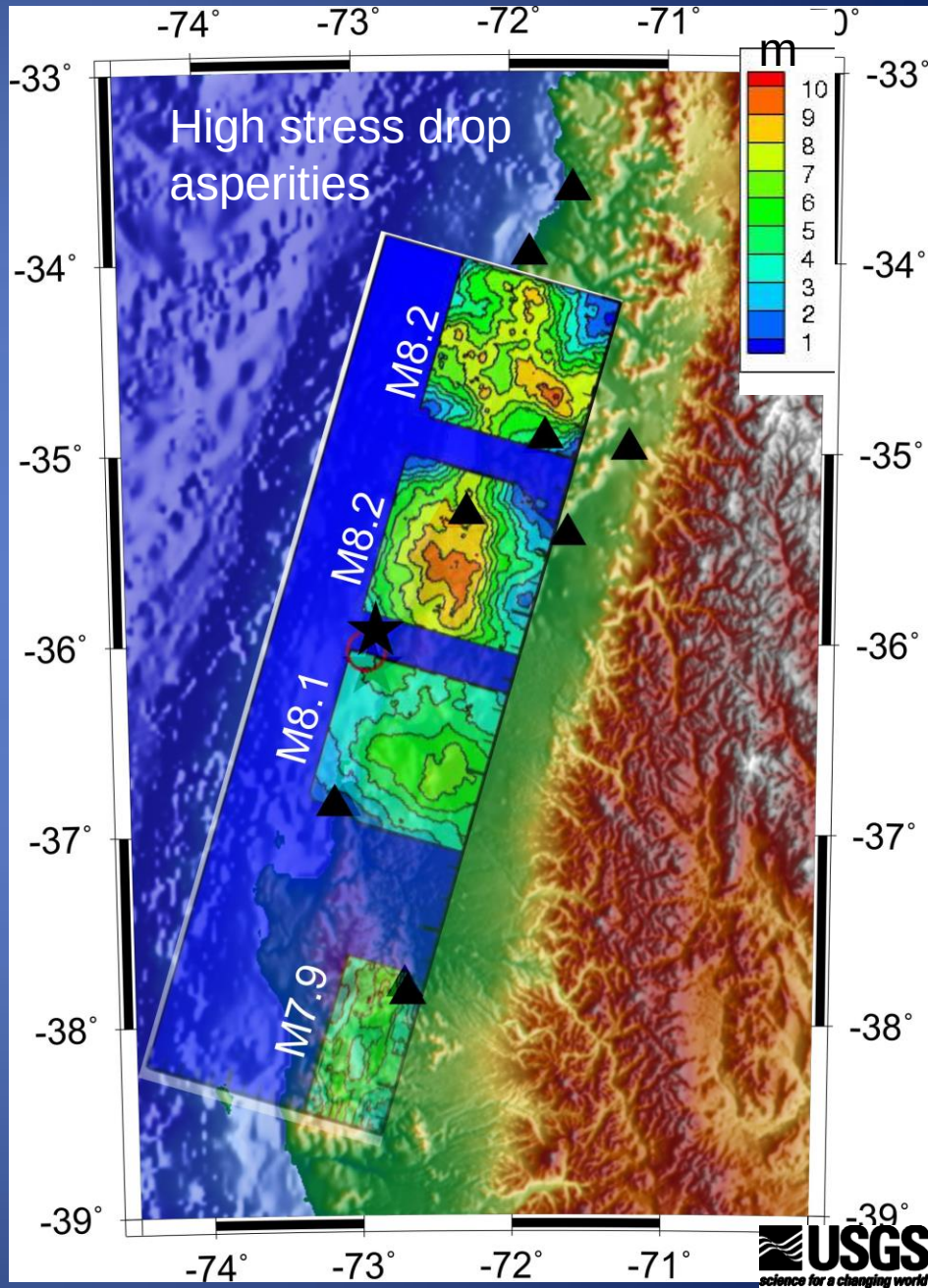


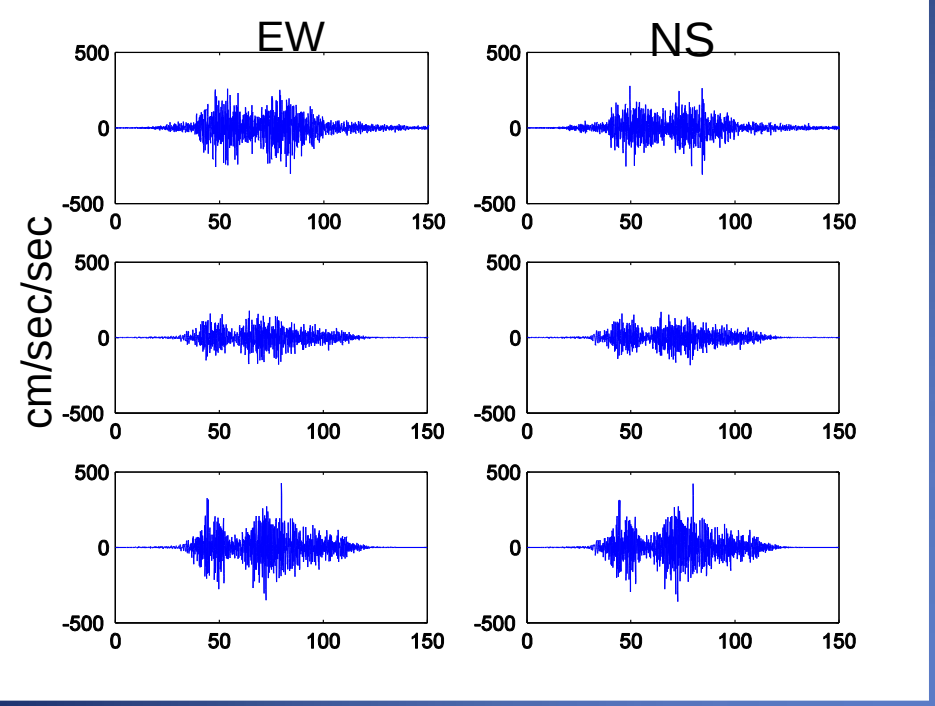
Compound source model for M8.8 Maule Chile Earthquake; these sources are additive

Background Slip with rise time of about 10 s



M8 Sub-Events with rise times about 2 s





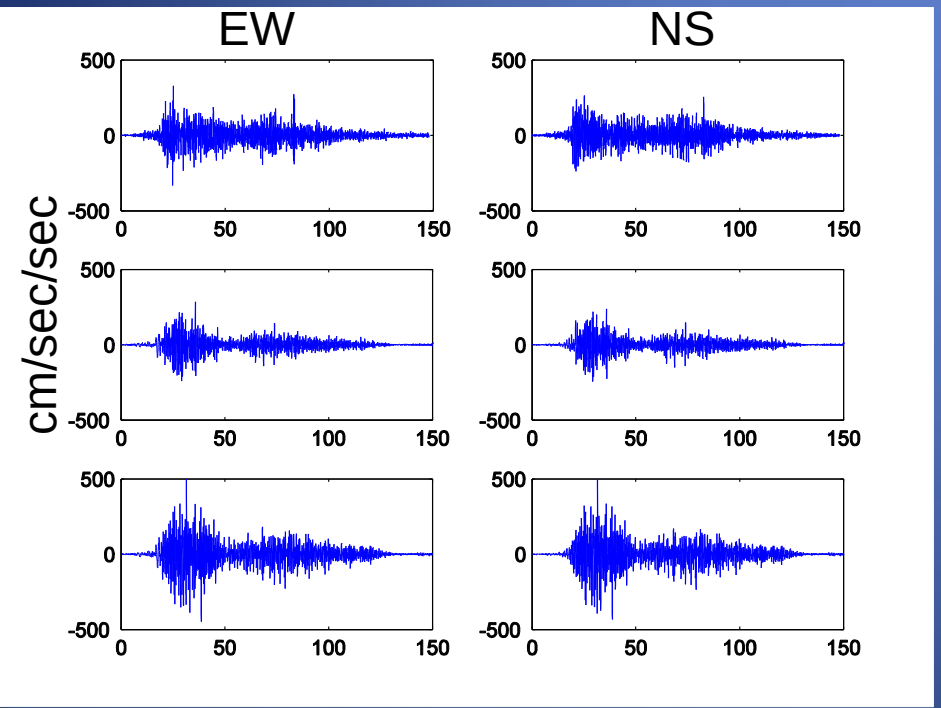
Station CUR, Vs30= 540 m/s (Kayen et al.)

Observed

All records 0.3-5Hz synthetics aligned with data (no trigger times)

Synthetics, 200 bar sub-events

Synthetics, 350 bar sub-events



Station TAL, Vs30= 550 m/s (Kayen et al.)

Observed

Synthetics, 200 bar sub-events

Synthetics, 350 bar sub-events

The M9 Project: University of Washington funded for 4 years by NSF

USGS is producing the synthetic seismograms for M9 Cascadia Earthquakes

Probabilistic Assessment of Hazard, including uncertainties

Synthetic seismograms produced from 3D simulations of M9 Cascadia earthquakes (Frankel)

Tsunami simulations for M9 Cascadia earthquakes (Gonzalez, LeVeque)

Supercomputer time provided by Pacific Northwest National Laboratory

Probabilistic Assessment of Impact

Evaluation of tall building response and damage from long-duration, long-period ground shaking (Berman, Eberhard, Marafi)

Evaluation of landslides and liquefaction from ground shaking (Duvall, Wartman, Kramer)

Evaluation of tsunami effects on structures near coast (Motley, LeVeque, Gonzalez)

Development of Shakemaps and tsunami-Inundation maps for emergency management, improving community resilience (Bostrum, Abramson)

Testing of Earthquake Early Warning (Vidale, Bodin)

Bill Stephenson developed the 3D velocity model for Cascadia. Used seismic refraction/refraction data and Delorey and Vidale (2011) model for Seattle basin, Moschetti et al. (2010) regional Vs, McCrory et al., plate interface

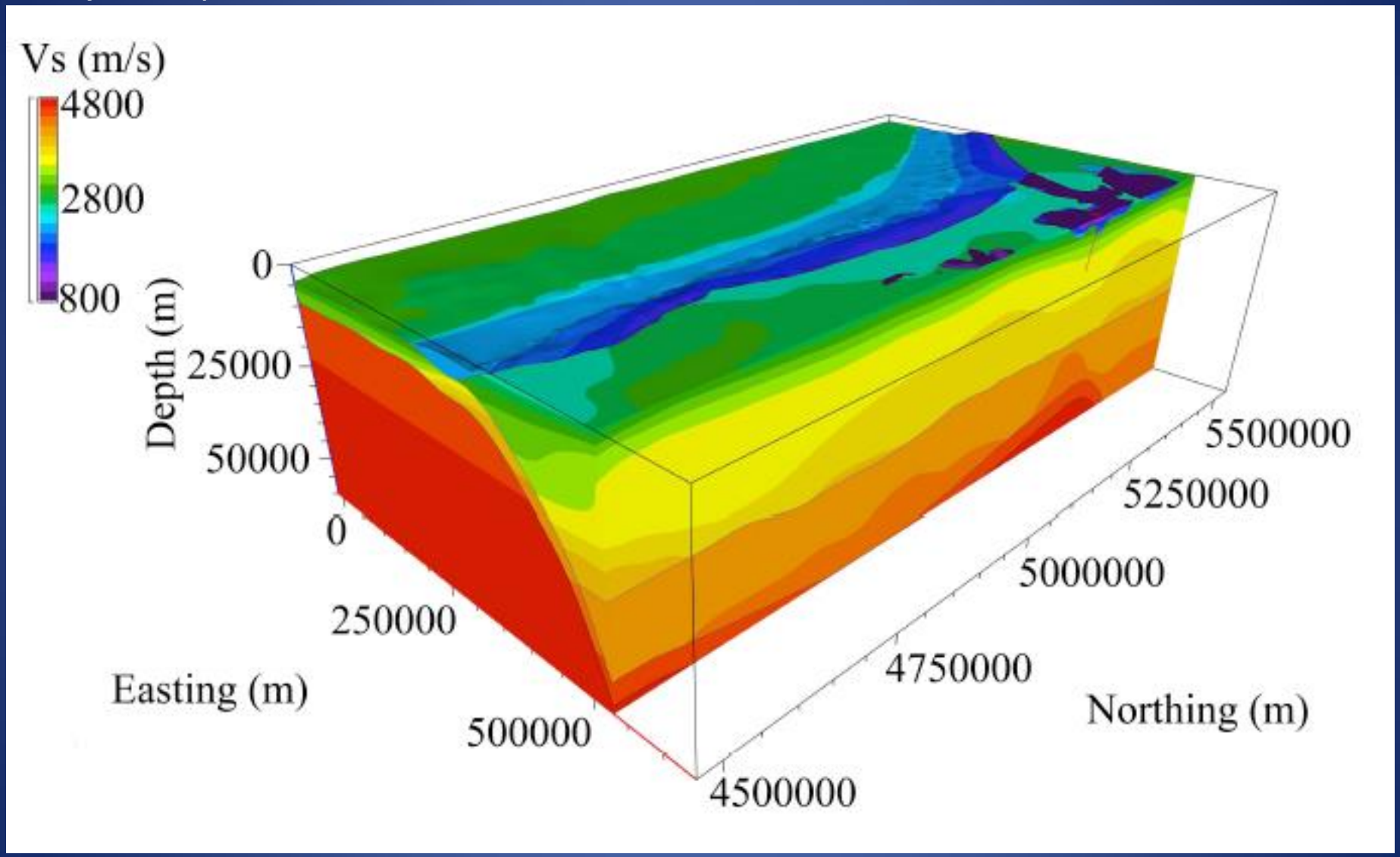
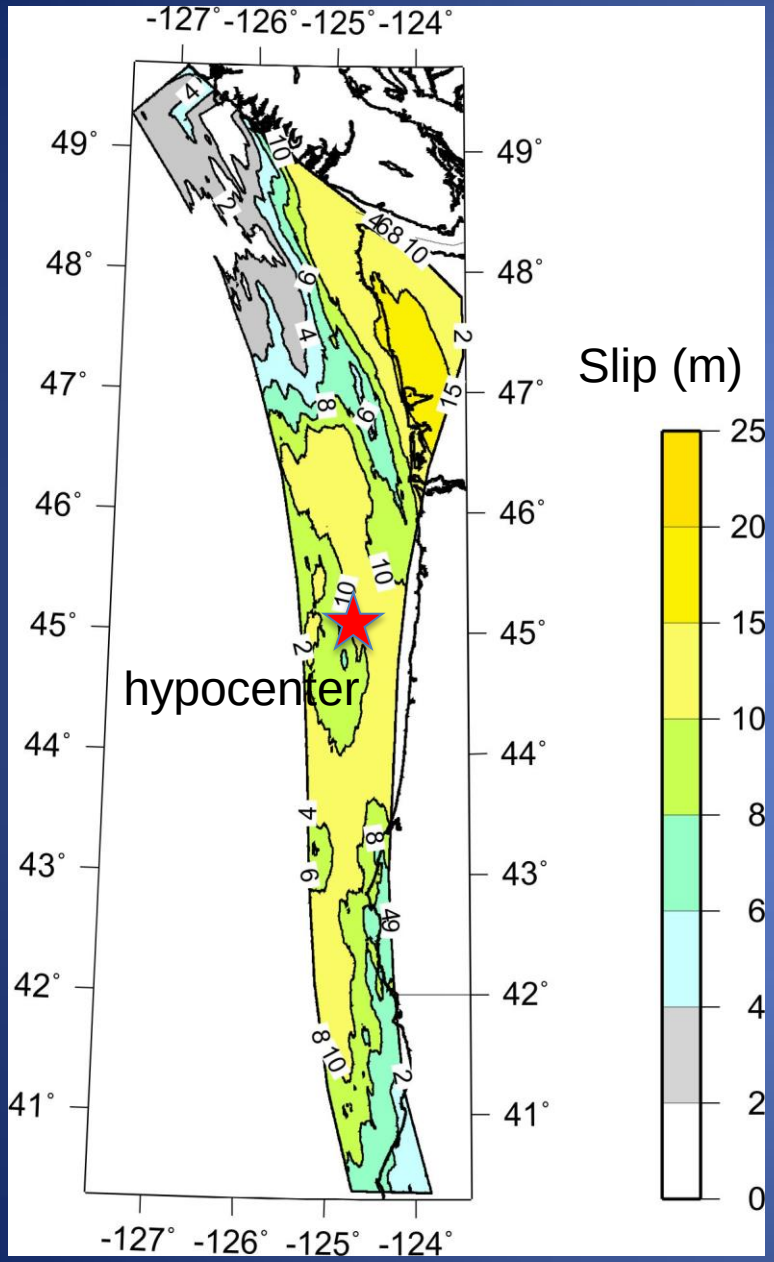
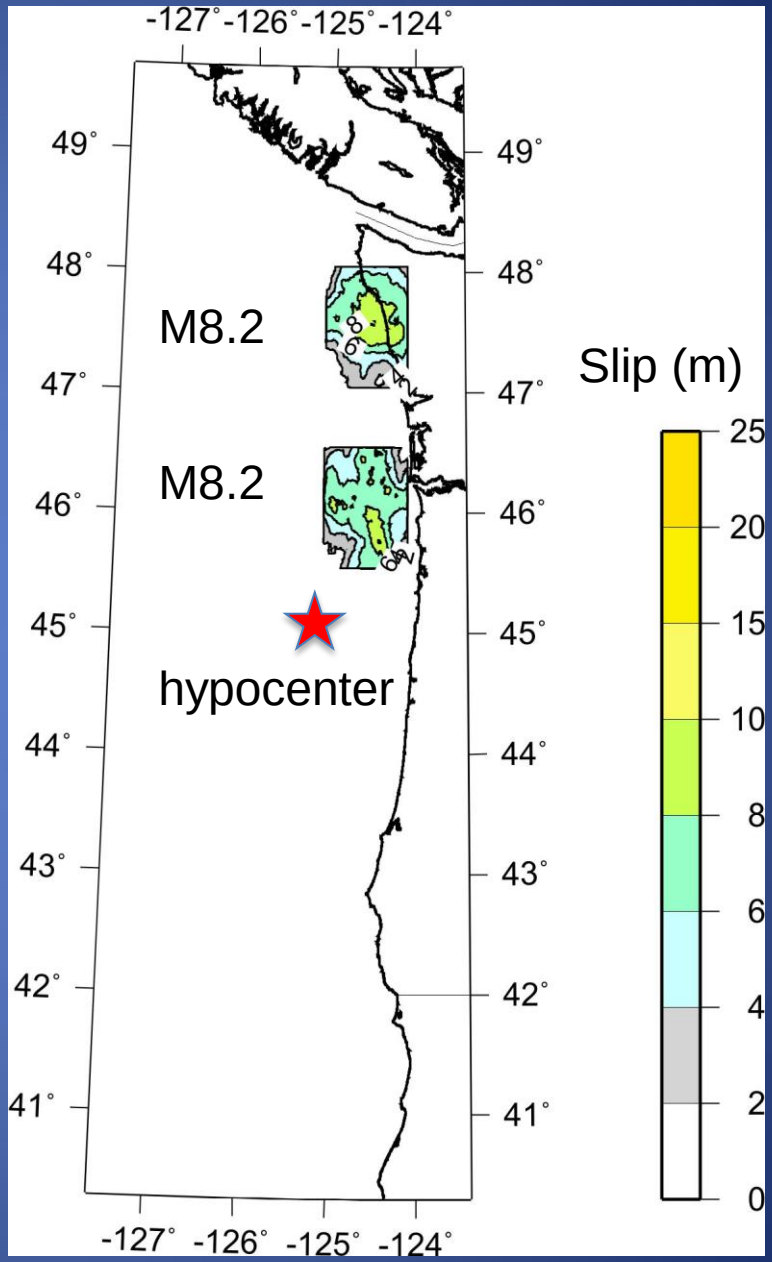


Figure from Delorey et al. (2014)

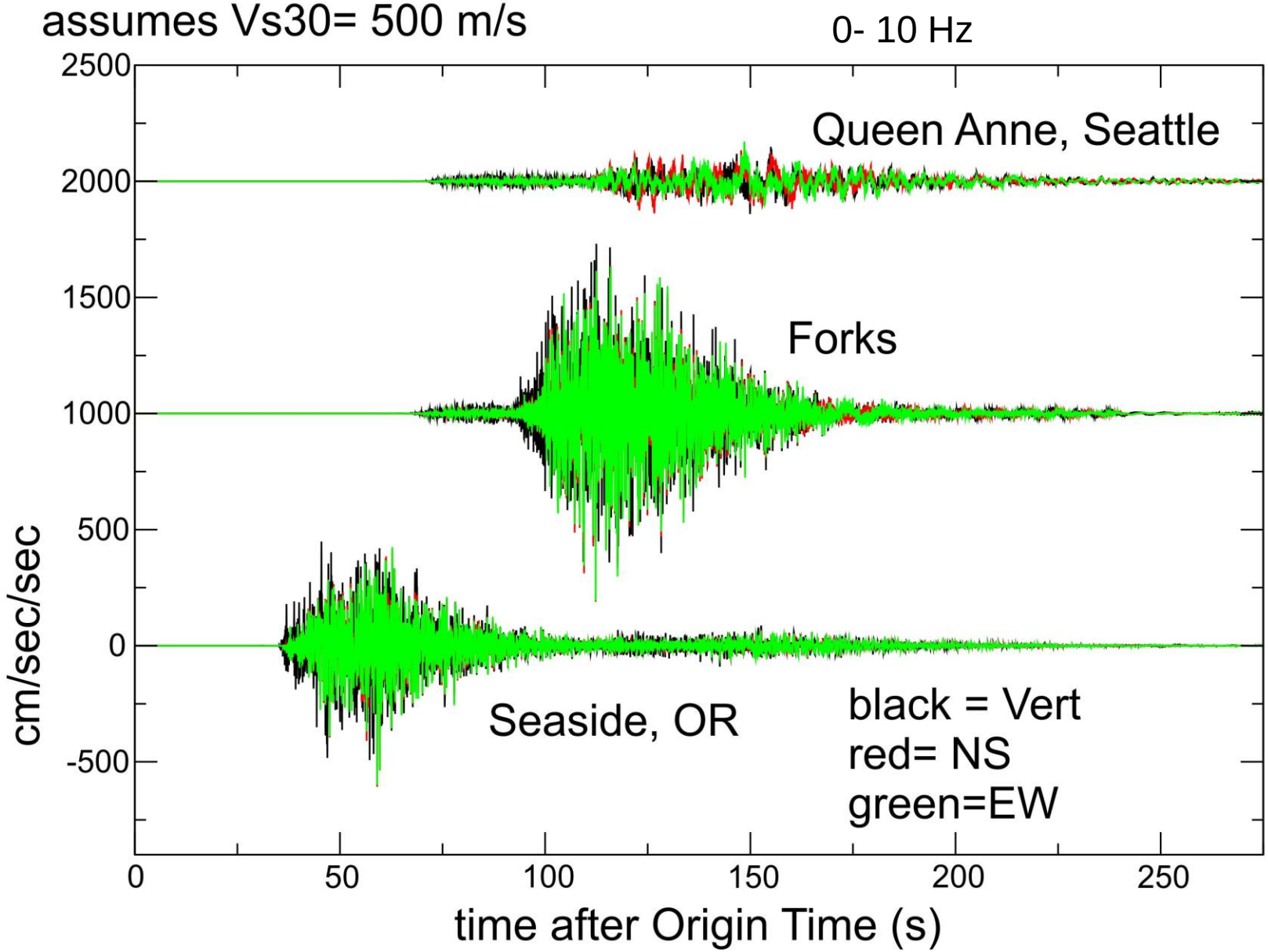
Trial slip distributions for M9 background slip (left); high stress drop sub-events (right)



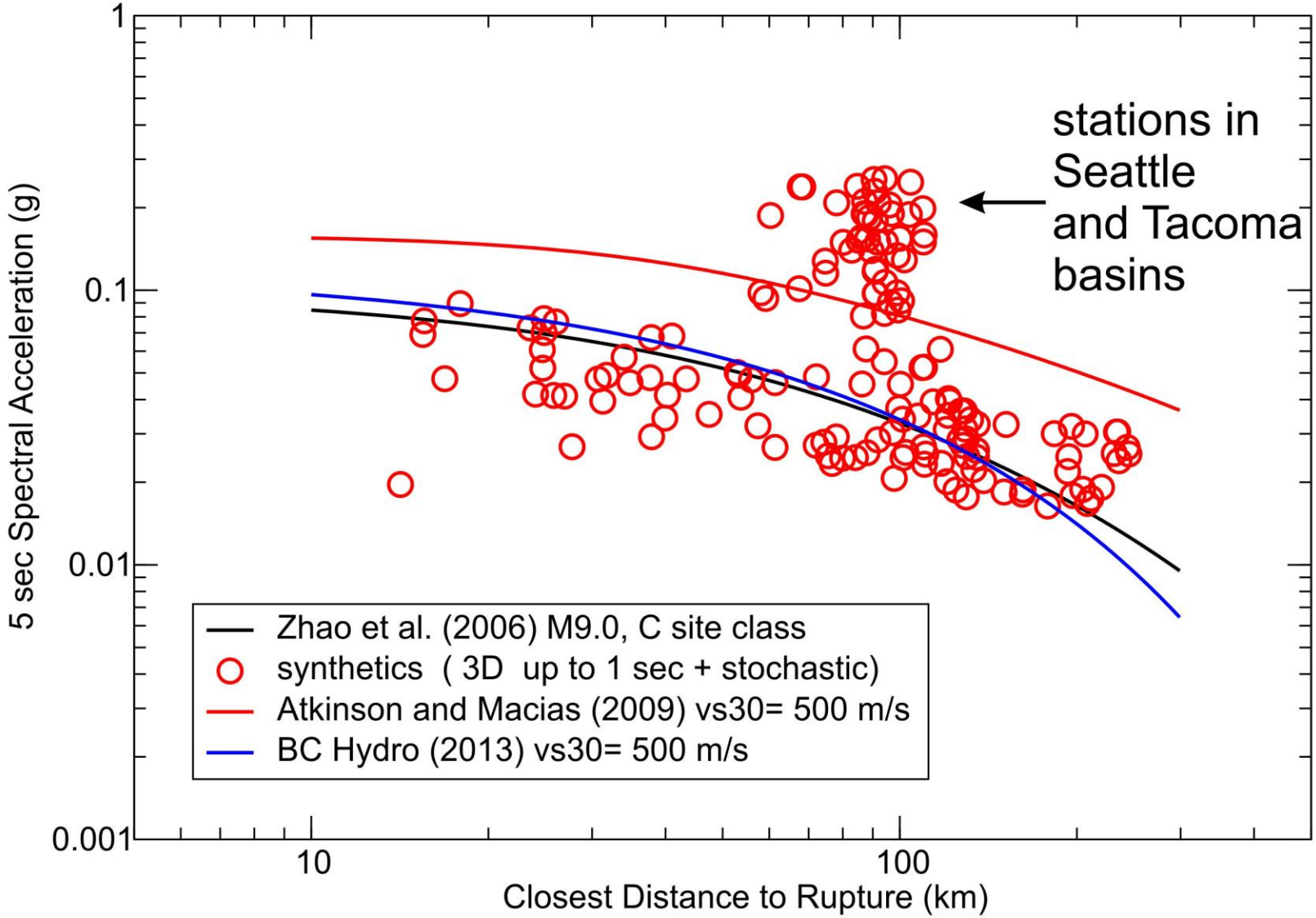


These sources are additive

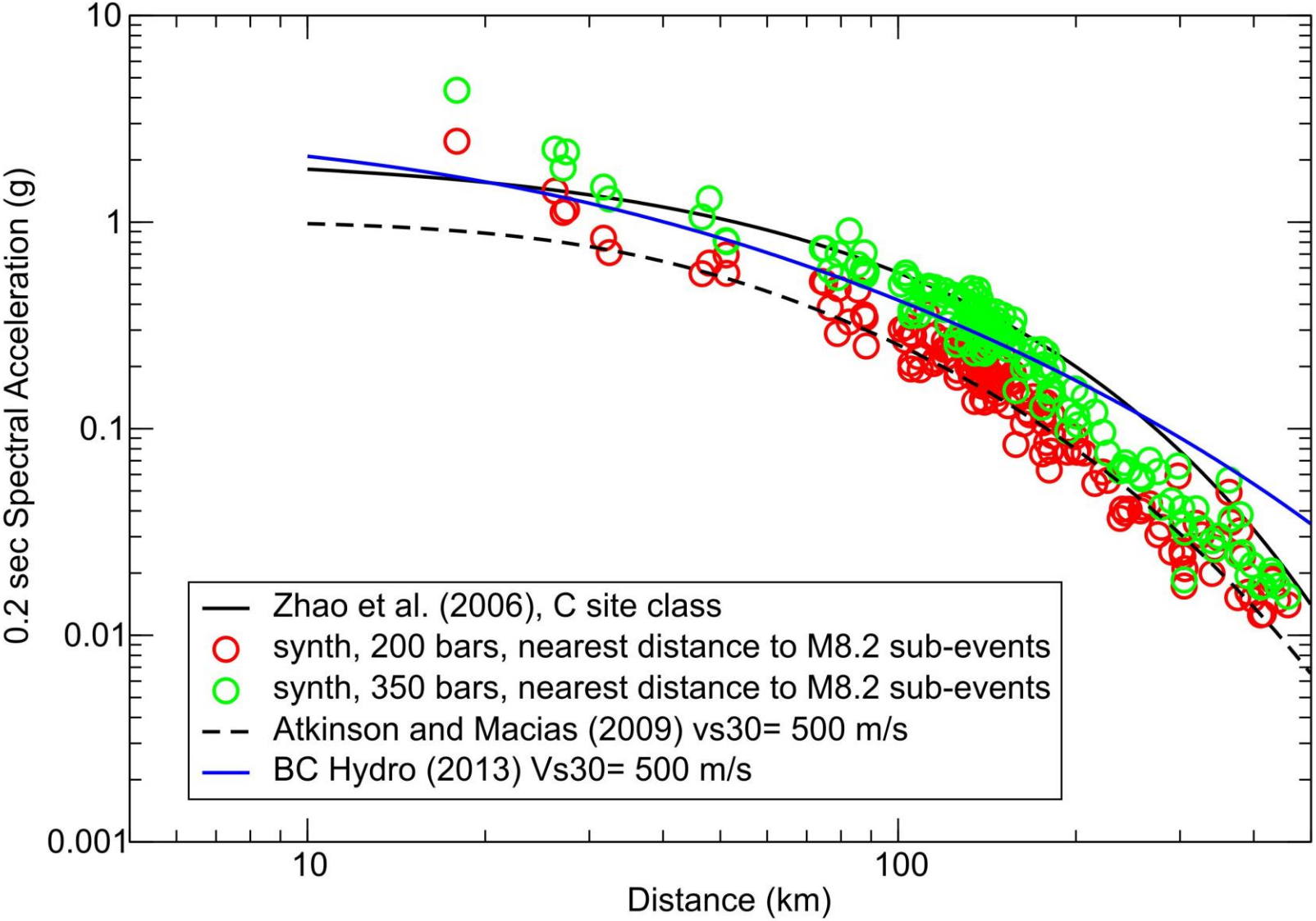
Synthetic acceleration records for M9.0 Cascadia Earthquake
assumes Vs30= 500 m/s



5 second response spectral accelerations
approximate natural period of a 50 story building



0.2 second response spectral accelerations approximate natural period of a 2 story building



Distance measured to nearest M8 sub-event

Summary

- 2014 Update of NSHM's uses new logic trees for Cascadia subduction zone. Some increase of hazard values in SW Oregon. Slight decrease of hazard values inland due to new subduction-zone GMPE's
- The USGS has many tools on the NSHM website that can be used for seismic hazard characterization for a region or site. (earthquake.usgs.gov/hazards)
- We are developing webtool to provide synthetic strong-motion time series (0-10 Hz) for M9 Cascadia earthquakes (M9 Project UW-USGS). Rupture models based on Tohoku and Maule observations. Uses 3D velocity model for Cascadia region

USGS
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