Logic Trees for the Cascadia Subduction Zone Used In the 2014 Update of the U.S. National Seismic Hazard Maps
+ M9 Slip Models

Art Frankel, USGS

Mark Petersen, USGS

Rui Chen, CGS

NTHMP-USGS workshop

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We convened three workshops of experts on the Cascadia Subduction Zone in 2010, 2011, 2012

- Recurrence relations for M8-9 earthquakes

  Workshop to evaluate turbidite evidence for great earthquakes: Nov 18-19, 2010, Corvallis (hosted by Chris Goldfinger). Summarized in USGS Open File Report 2011-1310. Brian Atwater wrote alternative to Goldfinger view (USGS OFR 2012-1043) and in Atwater et al. (2014) *Geology* paper.

- Location of down-dip edge of rupture zone

  Workshop: Dec 15, 2011, Eugene (co-convened with Ray Weldon)

- Pacific Northwest workshop for NSHM, March 21-22, 2012. Spent much of first day discussing and debating results of the earlier workshops and the consensus logic tree

Interpretation of rupture history of M8-9 earthquakes from 10,000 year record of turbidites (submarine deposits of turbulent flows of sand, silt, mud, and water)

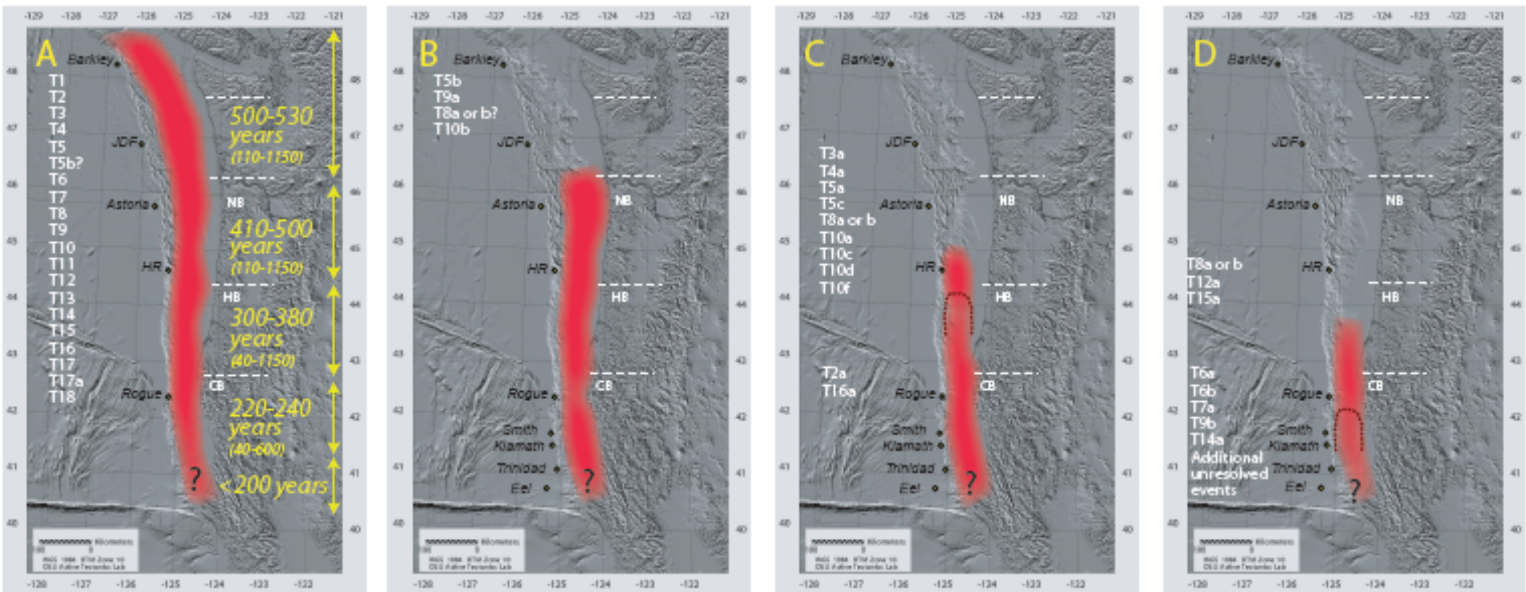
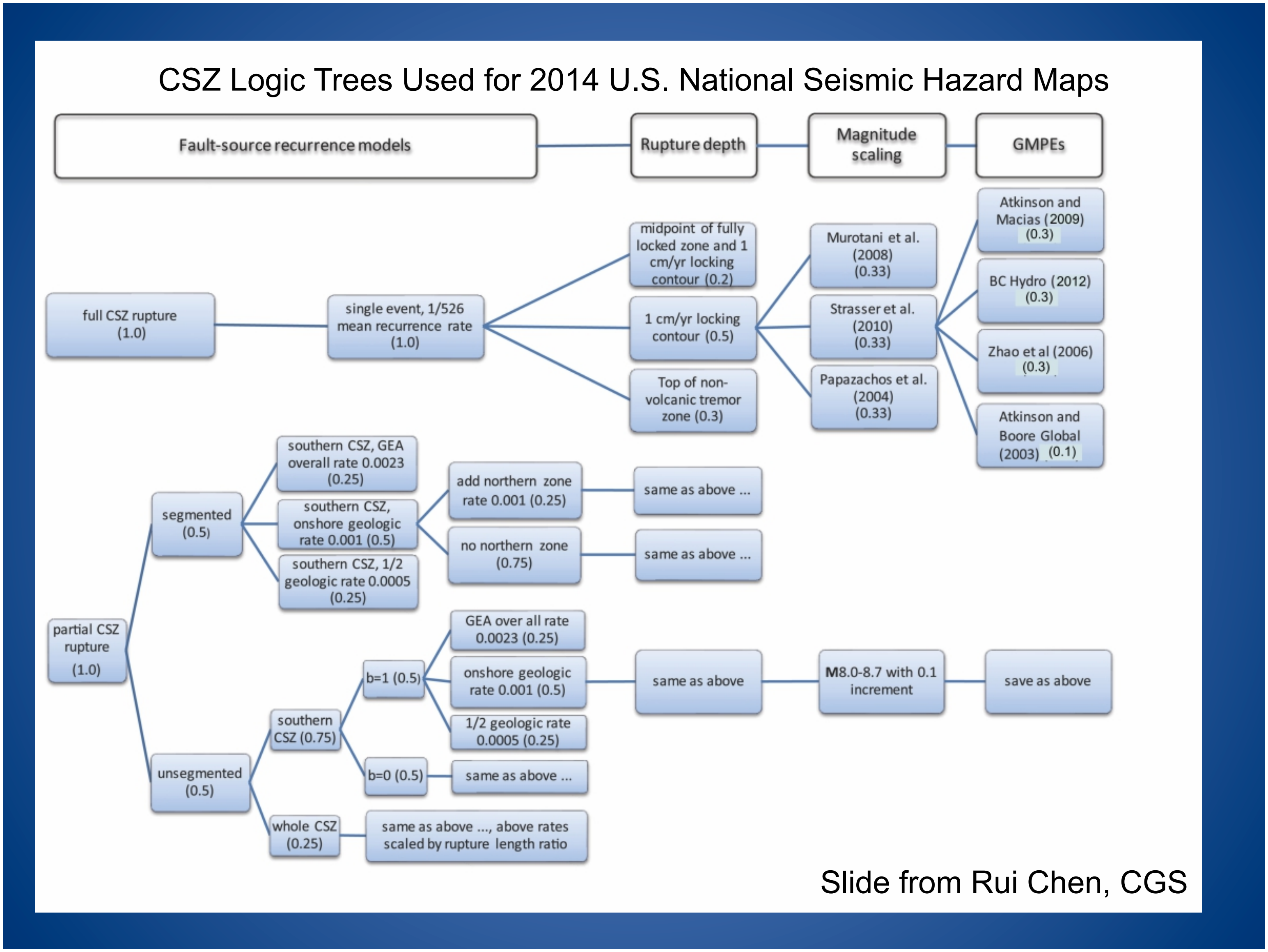


Figure from Goldfinger et al. (USGS Professional Paper 1661-F, 2012);


CSZ Logic Trees Used for 2014 U.S. National Seismic Hazard Maps
Fault-source recurrence models
Rupture depth
Magnitude scaling
GMPEs
full CSZ rupture (1.0)
single event, 1/526 mean recurrence rate (1.0)
midpoint of fully locked zone and 1 cm/yr locking contour (0.2)
1 cm/yr locking contour (0.5)
Top of non-volcanic tremor zone (0.3)
Murotani et al. (2008) (0.33)
Strasser et al. (2010) (0.33)
Papazachos et al. (2004) (0.33)
Atkinson and Macias (2009) (0.3)
BC Hydro (2012) (0.3)
Zhao et al (2006) (0.3)
Atkinson and Boore Global (2003) (0.1)
partial CSZ rupture (1.0)
segmented (0.5)
southern CSZ, GEA overall rate 0.0023 (0.25)
southern CSZ, onshore geologic rate 0.001 (0.5)
southern CSZ, 1/2 geologic rate 0.0005 (0.25)
add northern zone rate 0.001 (0.25)
no northern zone (0.75)
same as above ...
same as above ...
unsegmented (0.5)
southern CSZ (0.75)
whole CSZ (0.25)
b=1 (0.5)
b=0 (0.5)
GEA over all rate 0.0023 (0.25)
onshore geologic rate 0.001 (0.5)
1/2 geologic rate 0.0005 (0.25)
same as above ...
same as above ..., above rates scaled by rupture length ratio
same as above
M8.0-8.7 with 0.1 increment
save as above
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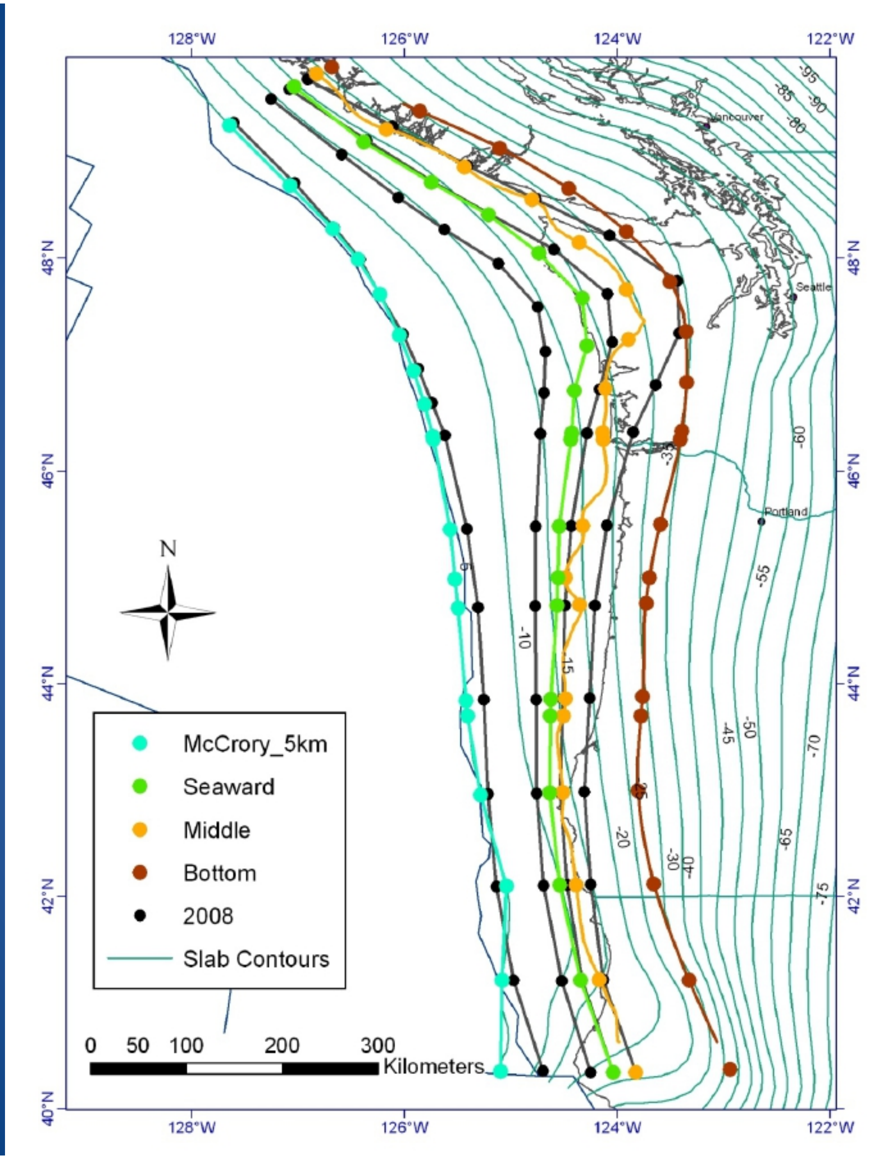

Models for
eastern, down-dip edge of
CSZ M8-9 rupture zones

Red: top of tremor zone
(0.3 wt)

Orange: 25% coupling
(1 cm/yr) from inversion of
GPS data (0.5 wt)

Green: midpoint of
locked zone from
thermal modeling
and 25% coupling
From GPS (0.2 wt)

Black lines are
previous models
from thermal modeling

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M Calculation Based on Rupture Area

		3D Rupture Area (km^2)	Papazachos et al. (2004)	Strasser et al. (2010)	Murotani et al. (2008)		Recur. (yr)
Case A	Top	84607.28	9.01	8.61	8.72		526
	Middle	106110.90	9.12	8.69	8.82		526
	Bottom	163956.66	9.34	8.85	9.01		526
Case B	Top	44503.94	8.68	8.37	8.44		2500
	Middle	53789.88	8.78	8.44	8.53		2500
	Bottom	94868.05	9.07	8.65	8.77		2500
Case C	Top	31917.12	8.52	8.25	8.30		1111
	Middle	39003.30	8.62	8.33	8.39		1111
	Bottom	71176.63	8.92	8.55	8.65		1111
Case D	Top	21797.47	8.32	8.11	8.13		1000
	Middle	26703.54	8.43	8.19	8.22		1000
	Bottom	51055.54	8.75	8.42	8.50		1000

M_o is moment in Nm. To convert to magnitude use: $\log M_o = 1.5M + 9.05$

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

USGS is producing broadband (0-10 Hz) synthetic seismograms for M9 Cascadia earthquakes; considering a range of rupture scenarios

Probabilistic Assessment of Hazard, including uncertainties

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

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, Greenfield, Grant)

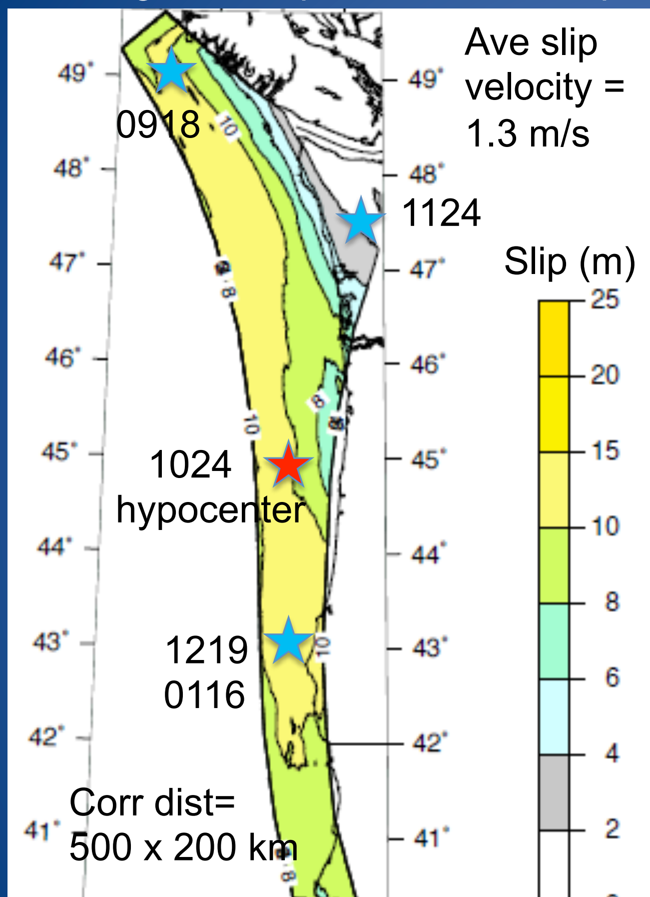
Evaluation of tsunami effects on structures near coast (Motley, LeVeque, Gonzalez)

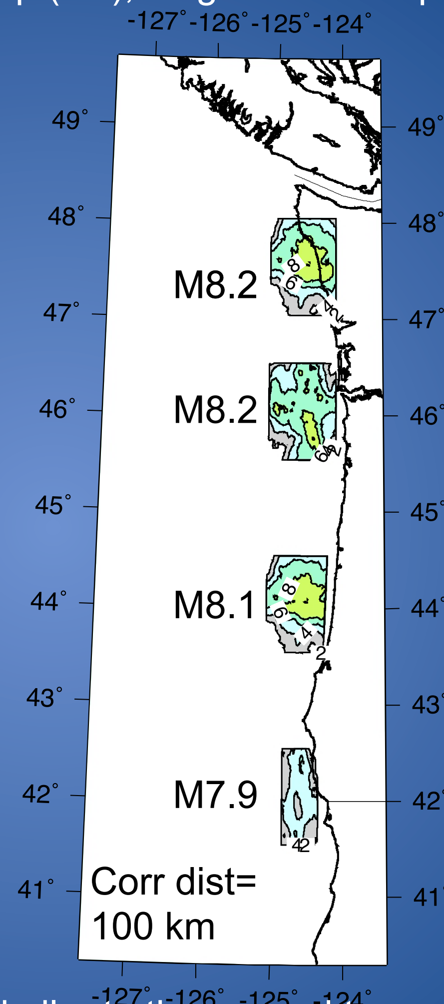
Development of Shakemaps and tsunami-Inundation maps for emergency management, improving community resilience (Bostrum, Abramson)

Testing of Earthquake Early Warning (Vidale, Bodin)

Compound rupture model: background slip (left); high stress drop sub-events (right)

Background slip with slow buildup





Ave slip velocity = 5.4 m/s

M9.0 slip Model used For M9 Project With University of Washington

These sources are additive; sub-events similar to those used to model M8.8 Maule strong-motion records

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Some Future Studies Needed To Better Determine Recurrence Times and Source Zones for M8-9 CSZ earthquakes

- Additional coring of marine sediments to better understand origin of mud turbidites and their spatial-temporal correlations; also need better understanding of turbidite records in northern CSZ; investigate possibility of triggering of turbidites by M7 Gorda plate earthquakes or crustal earthquakes
- Additional onshore paleoseismology and paleogeodesy to better determine history of M8-9 CSZ earthquakes
- Investigate possibility of M9 Tohoku type rupture with very large slip and shorter rupture zone

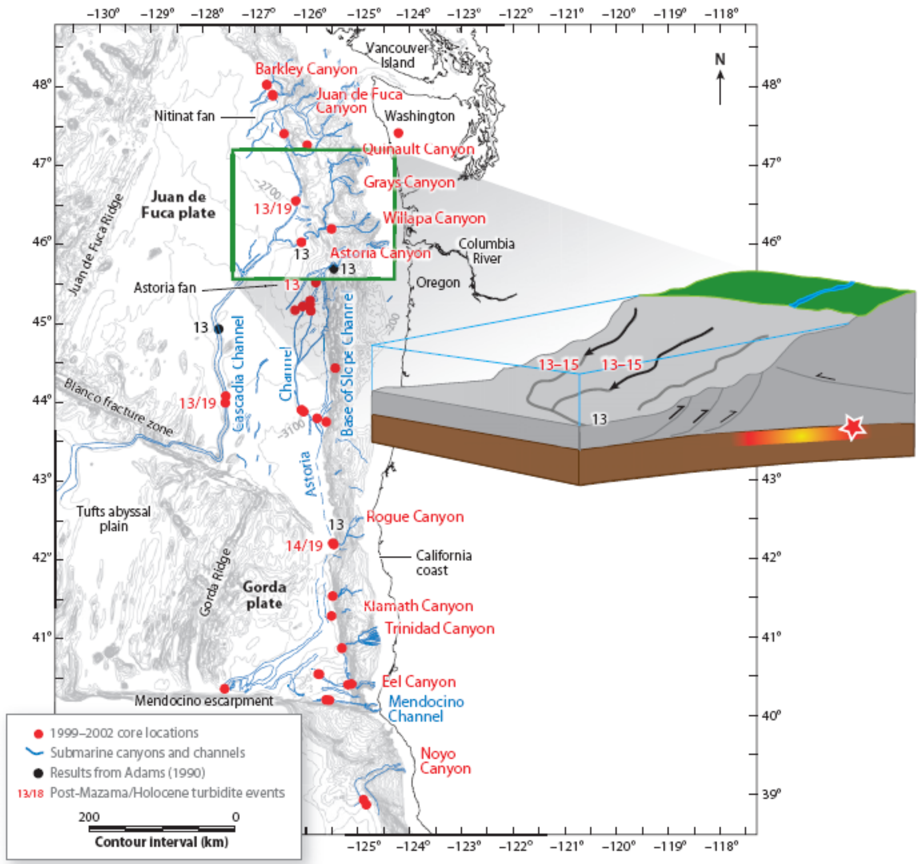


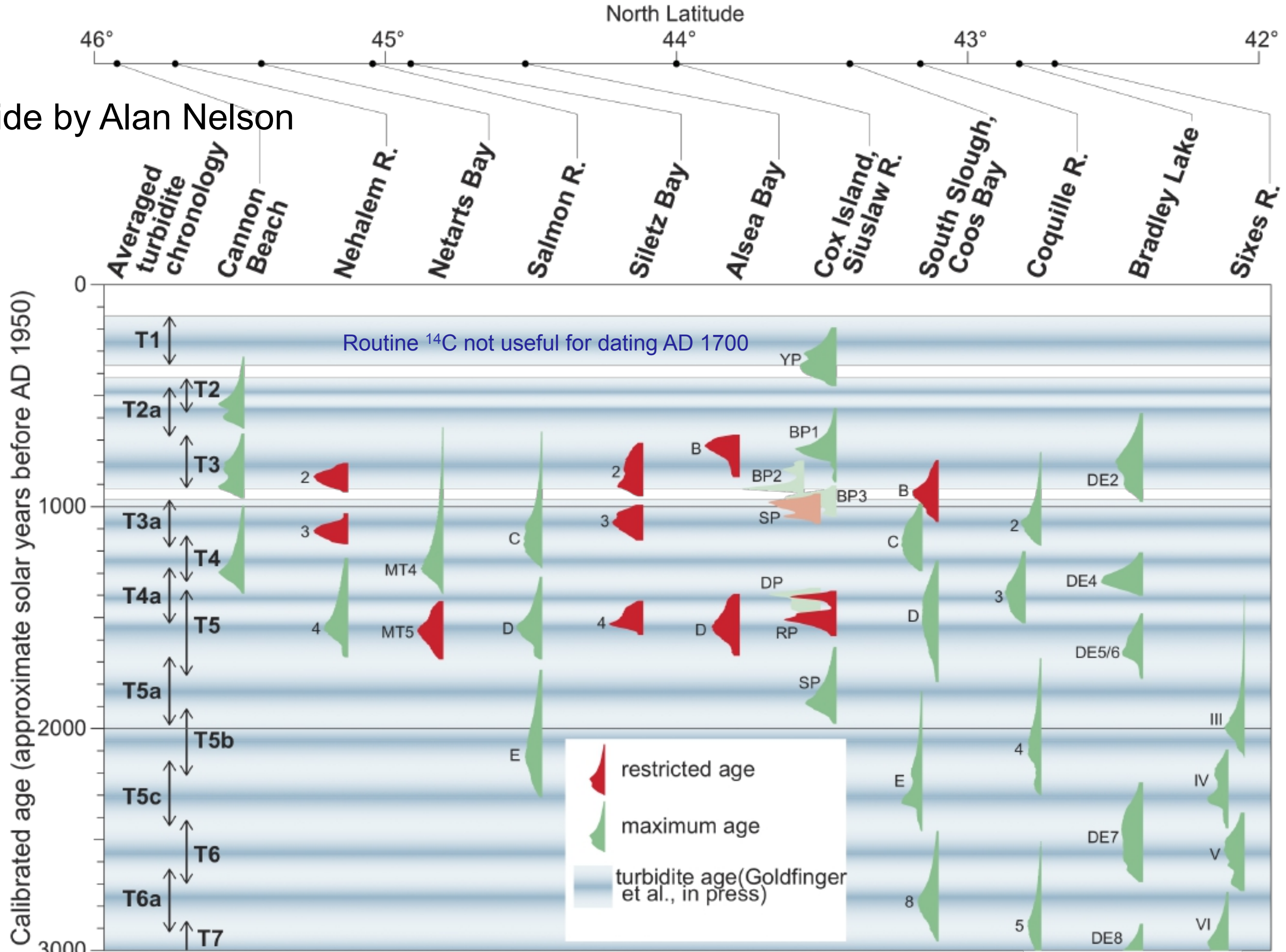
Figure 6

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)

submarine channels and locations of cores

Slide by Alan Nelson



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

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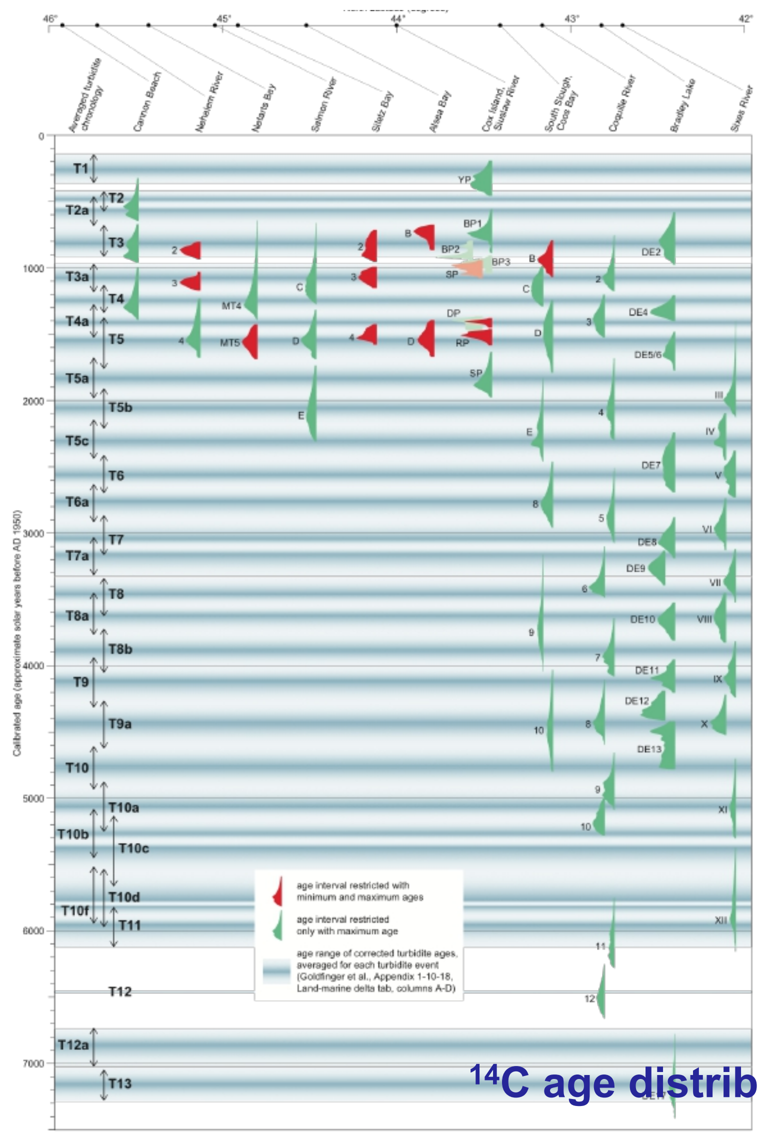
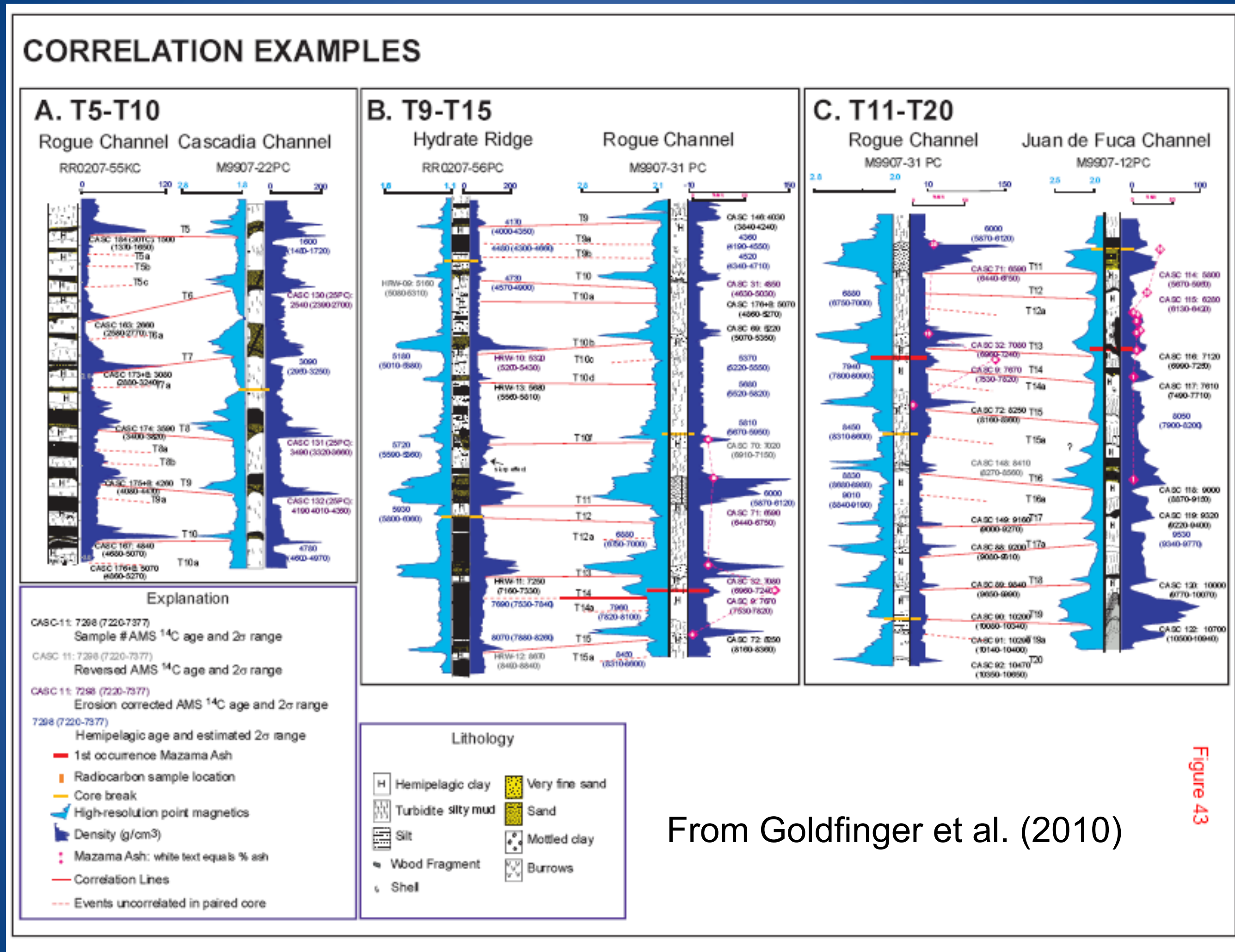


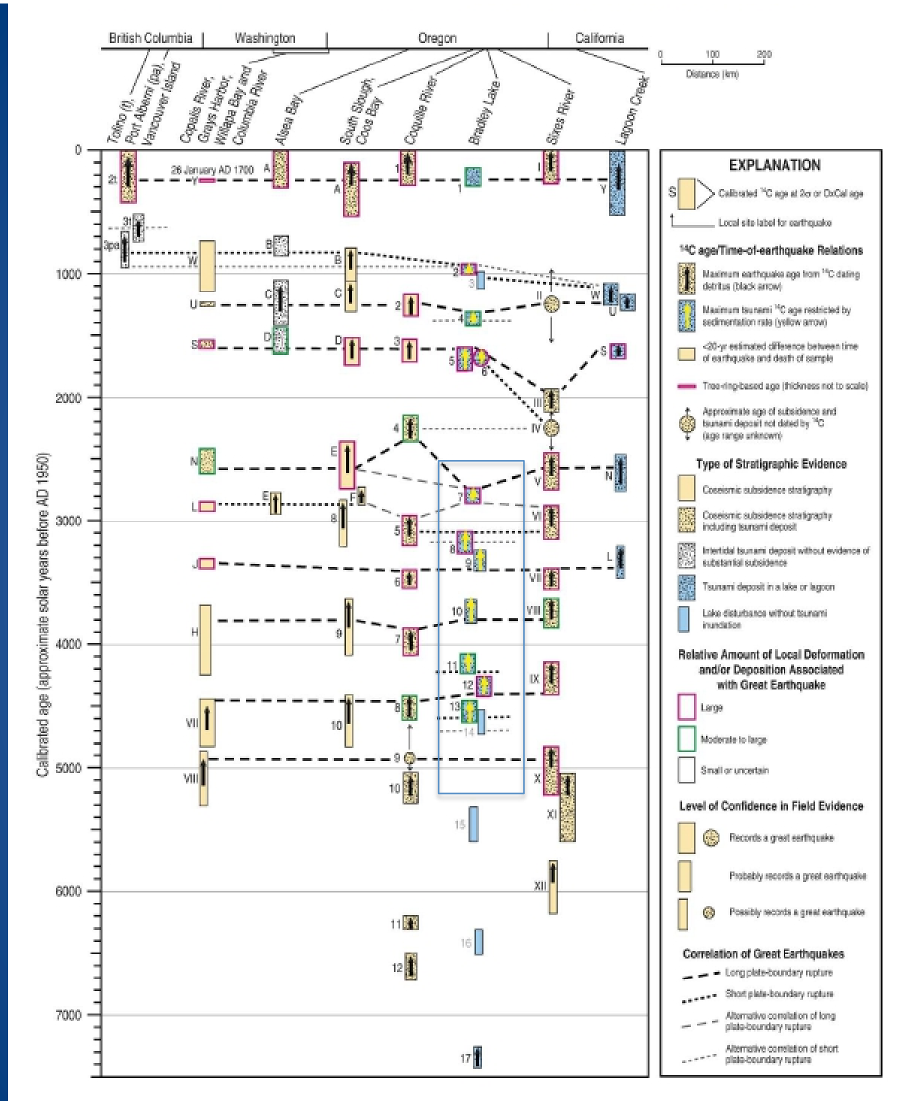
Figure 1. — Nelson, Engelhart, and Bradley for Cascadia turbidites and earthquake recurrence workshop, Corvallis, OR—18-19 Nov 2010

^{14}C age distributions

Slide from Alan Nelson



From Goldfinger et al. (2010)



Compilation of on land paleoseismic data

From Nelson et al. (2006)

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- Included hazard from great Cascadia earthquakes since 1996 NSHM's.
- Used recurrence rate derived from on-shore paleoseismology (e.g., Atwater and Hemphill-Haley)
- Allowed for whole CSZ rupture M9 and partial rupture M8's.