Recurrence Models for Cascadia M8-9 Earthquakes Used in National Seismic Hazard Maps and ASCE 7-16 Tsunami Inundation Maps

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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

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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)

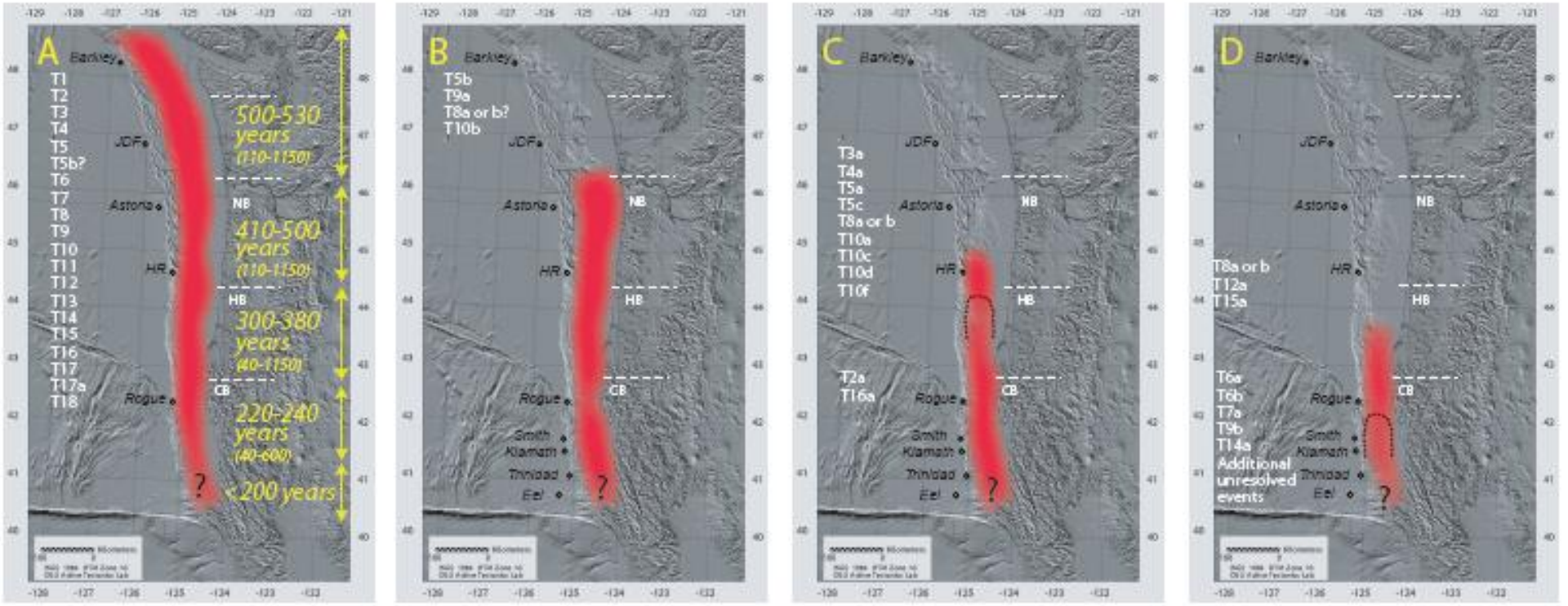
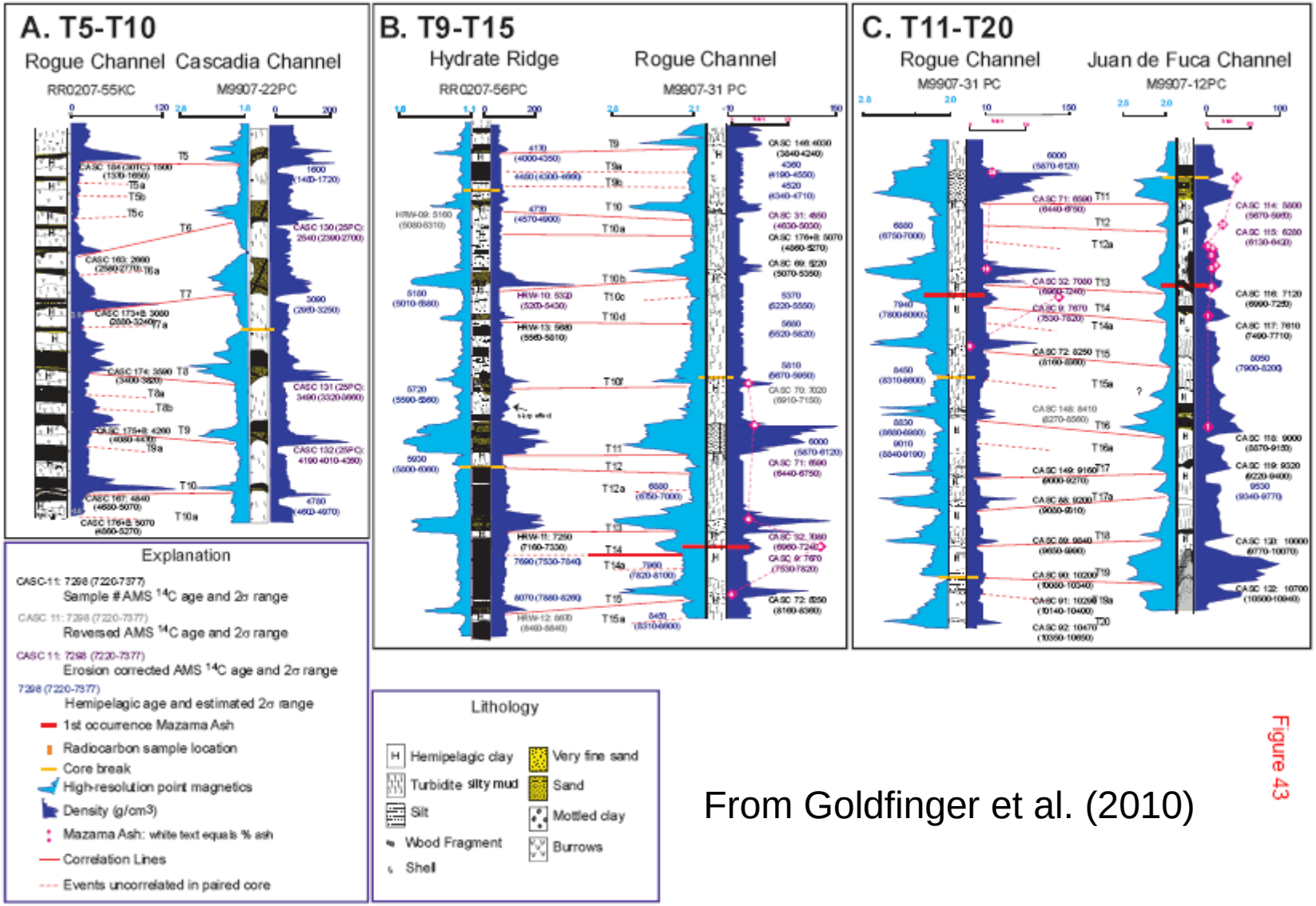


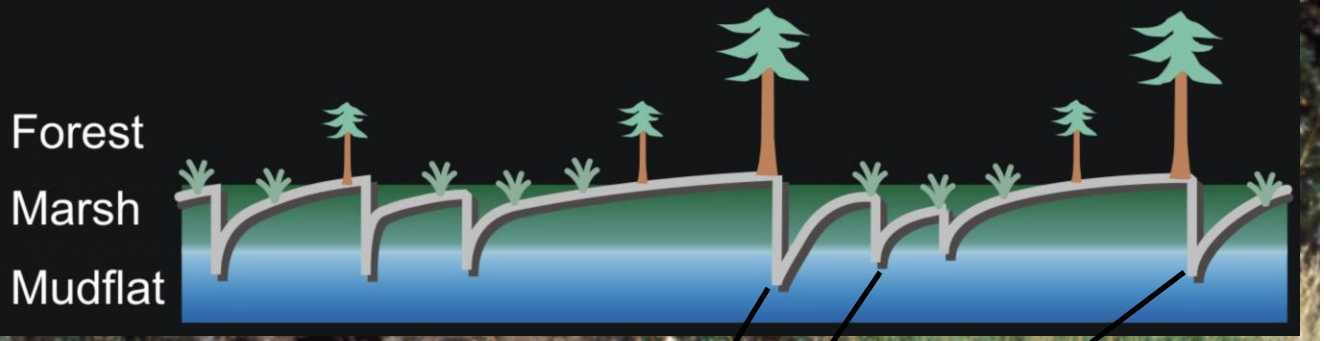
Figure from Goldfinger et al. (USGS Professional Paper 1661-F, 2012);

CORRELATION EXAMPLES



From Goldfinger et al. (2010)

Figure 43



AD 1700

1300 BP

1600 BP

Brian Atwater for scale

USGS estimates a 10-14% chance of a Cascadia M9 earthquake In the next 50 years (Petersen et al., 2002)

Slide modified from Alan Nelson

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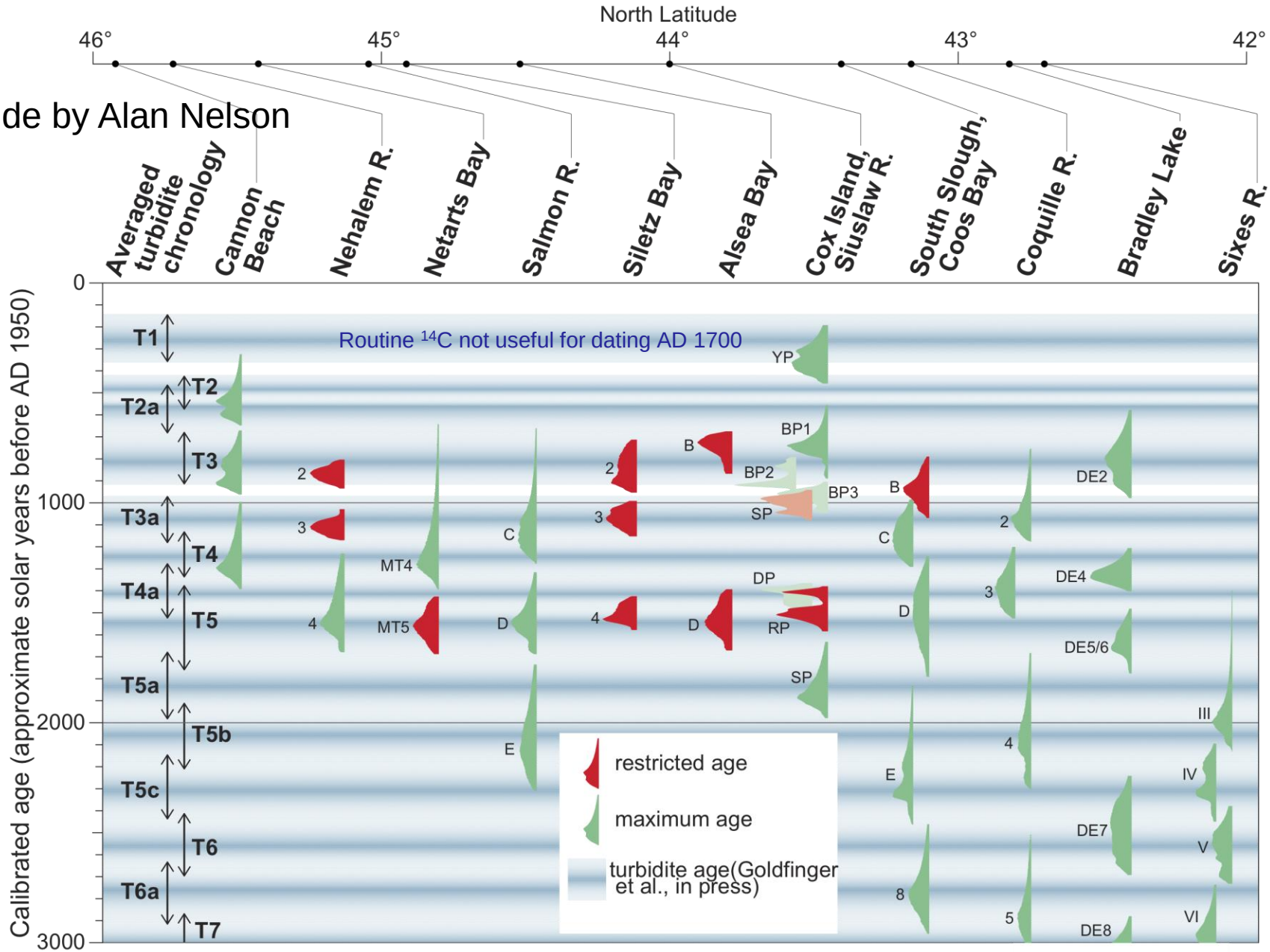
Earthquake stratigraphy exposed in southern Washington, Niawiakum River estuary

Slide by Alan Nelson



radiocarbon age distributions of M8-9 Cascadia earthquakes from onshore locations plotted with ages of earthquakes inferred from marine turbidites

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Consensus from 2010 workshop on ruptures that involve entire length of CSZ

- These occur with an average recurrence time of 500-550 years. Most of these would have magnitudes around 9. Turbidite and on-shore data agree on these rates, but there are some discrepancies for individual events
- Some of these 500 year “events” may be sequences of M8 earthquakes that fill up the CSZ over a period of a few decades or less (disagreement about how often this occurs)

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2010 and 2012 workshops developed multiple recurrence models for M8 earthquakes in southern CSZ

- Reconciling offshore and onshore data sets, each with strengths and weaknesses.
- Mean value of models is about 10 partial rupture events in past 10,000 years (half of number in Goldfinger et al., in 2012). Some workshop participants questioned 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) in limited time periods was indicative of M8+ earthquakes that ruptured only the southern CSZ
- Implies average 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)

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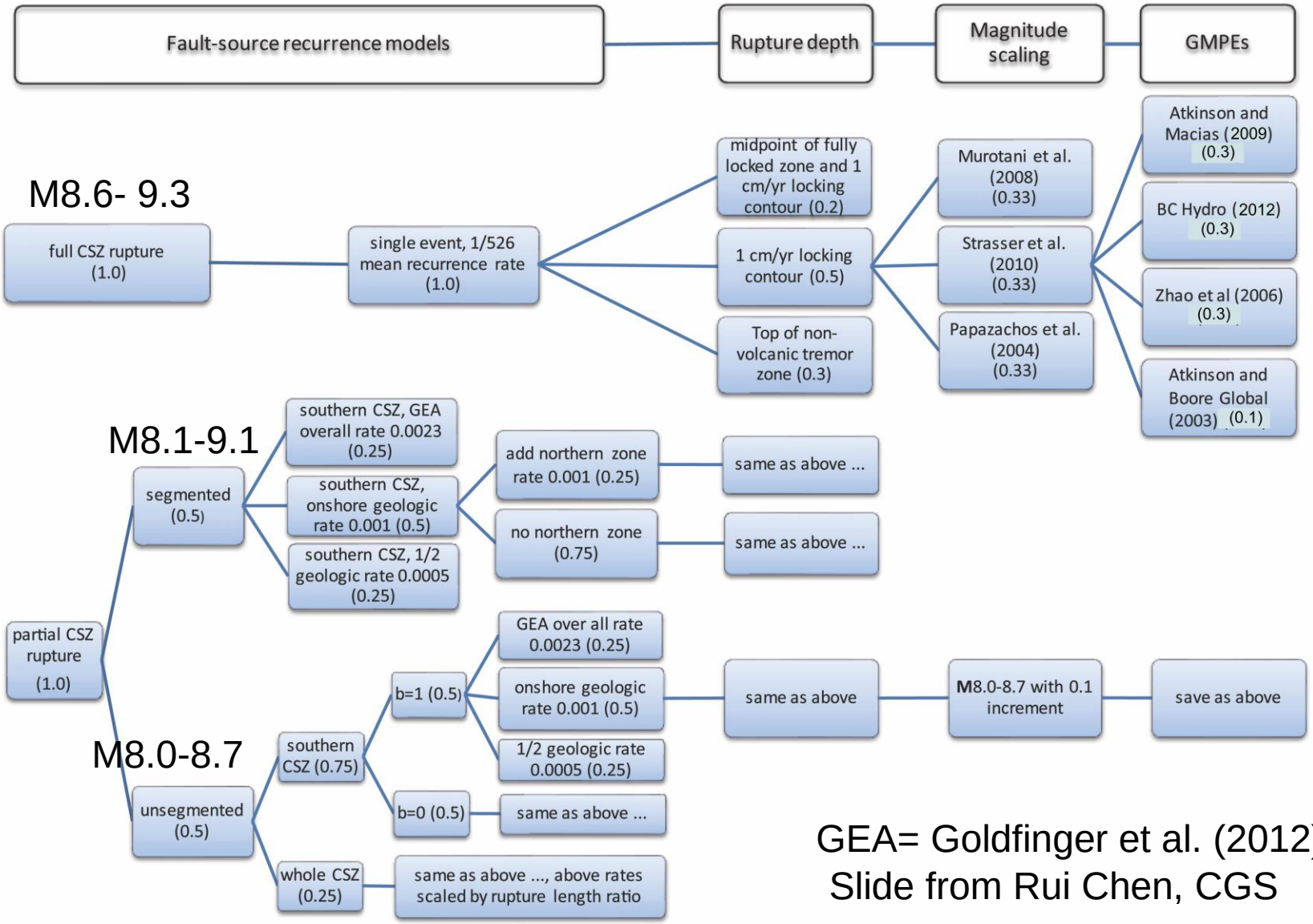
CSZ Logic Trees Used for 2014 and 2018 U.S. National Seismic Hazard Maps



GEA= Goldfinger et al. (2012)
Slide from Rui Chen, CGS

See USGS OFR 2014-1091

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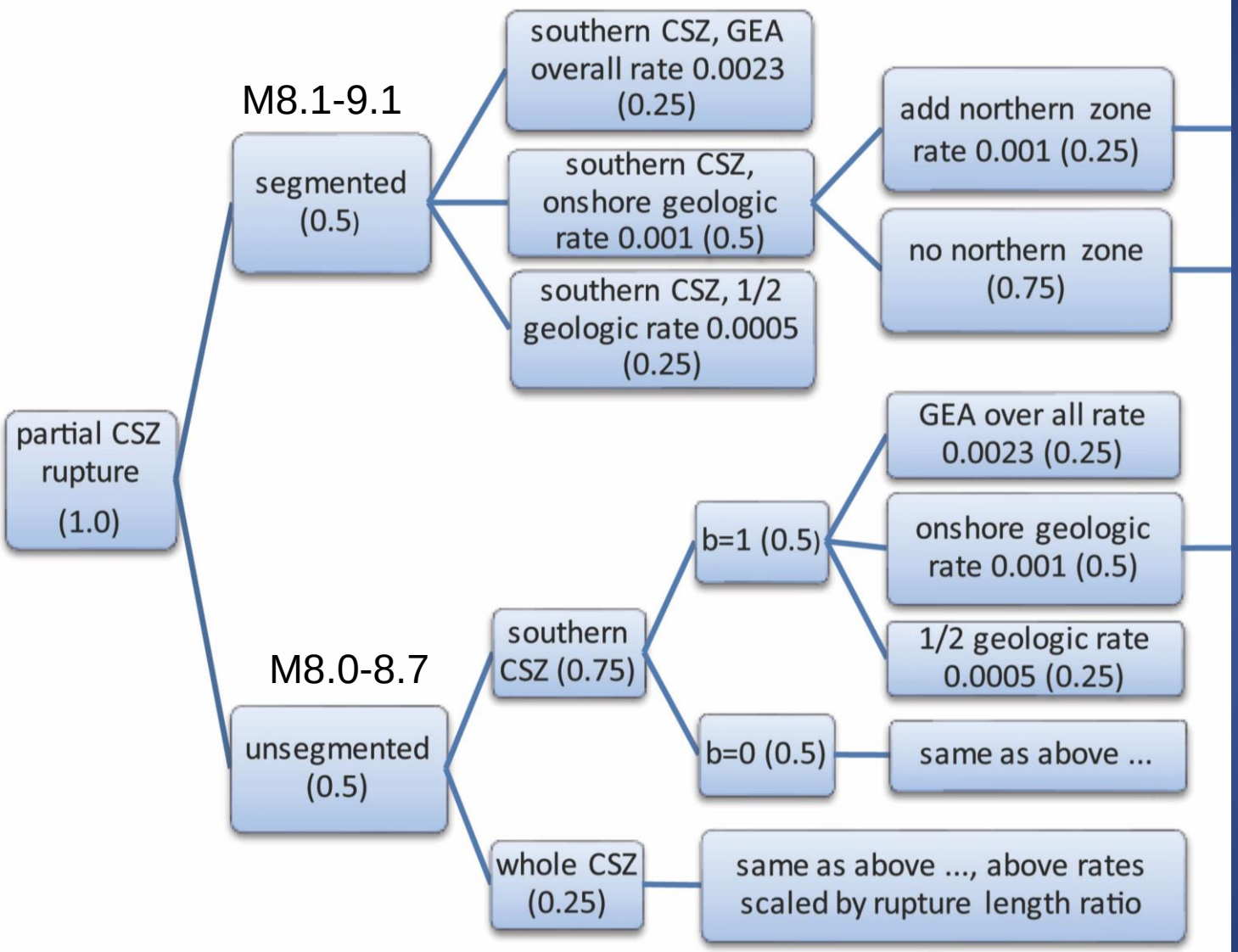
Part of Logic Tree Used for 2014 and 2018 NSHMs



GEA= Goldfinger et al. (2012)

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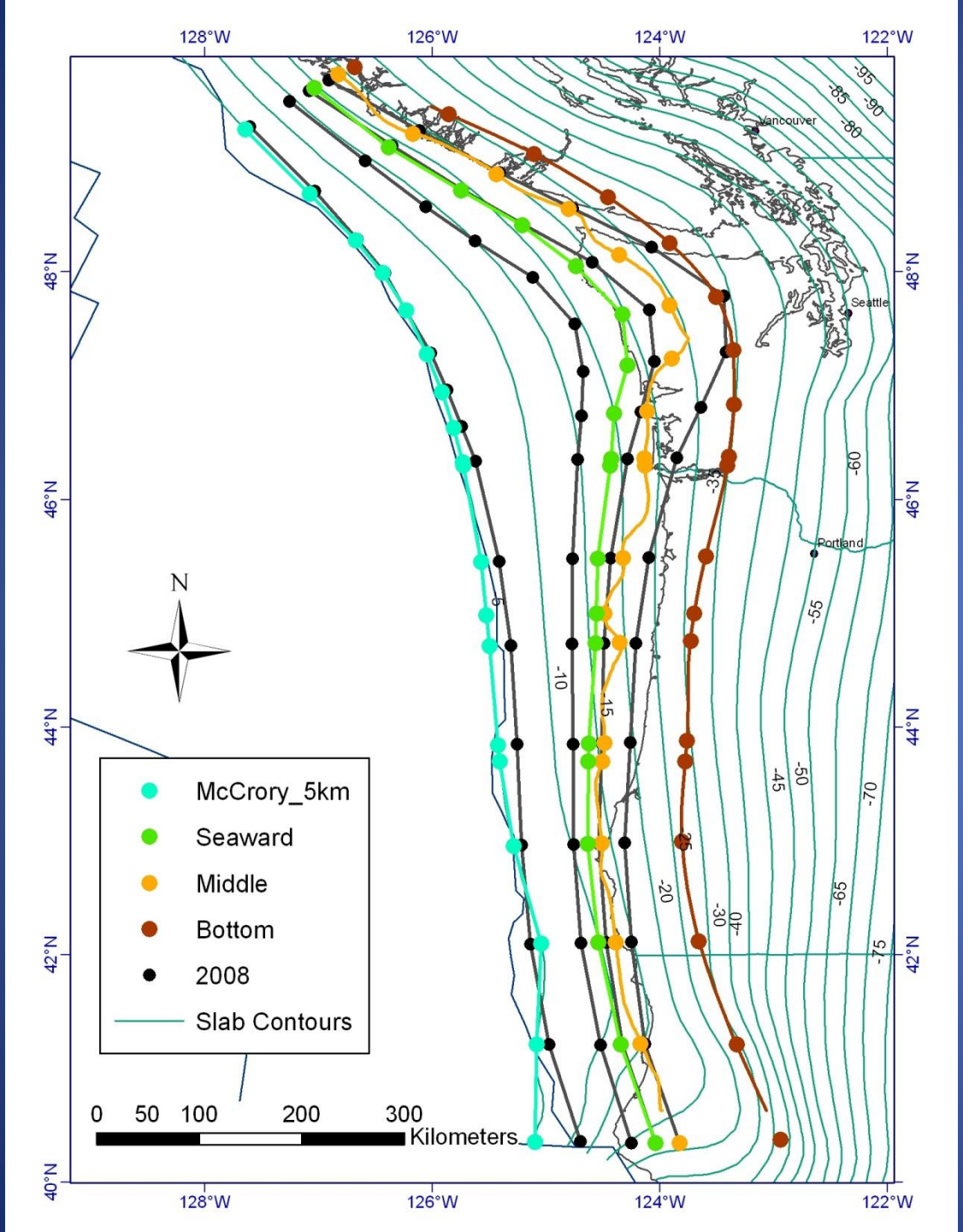

Models for
eastern, down-dip edge of
CSZ M8-9 rupture zones

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

Slide from
Rui Chen, CGS
USGS OFR 2014-1091

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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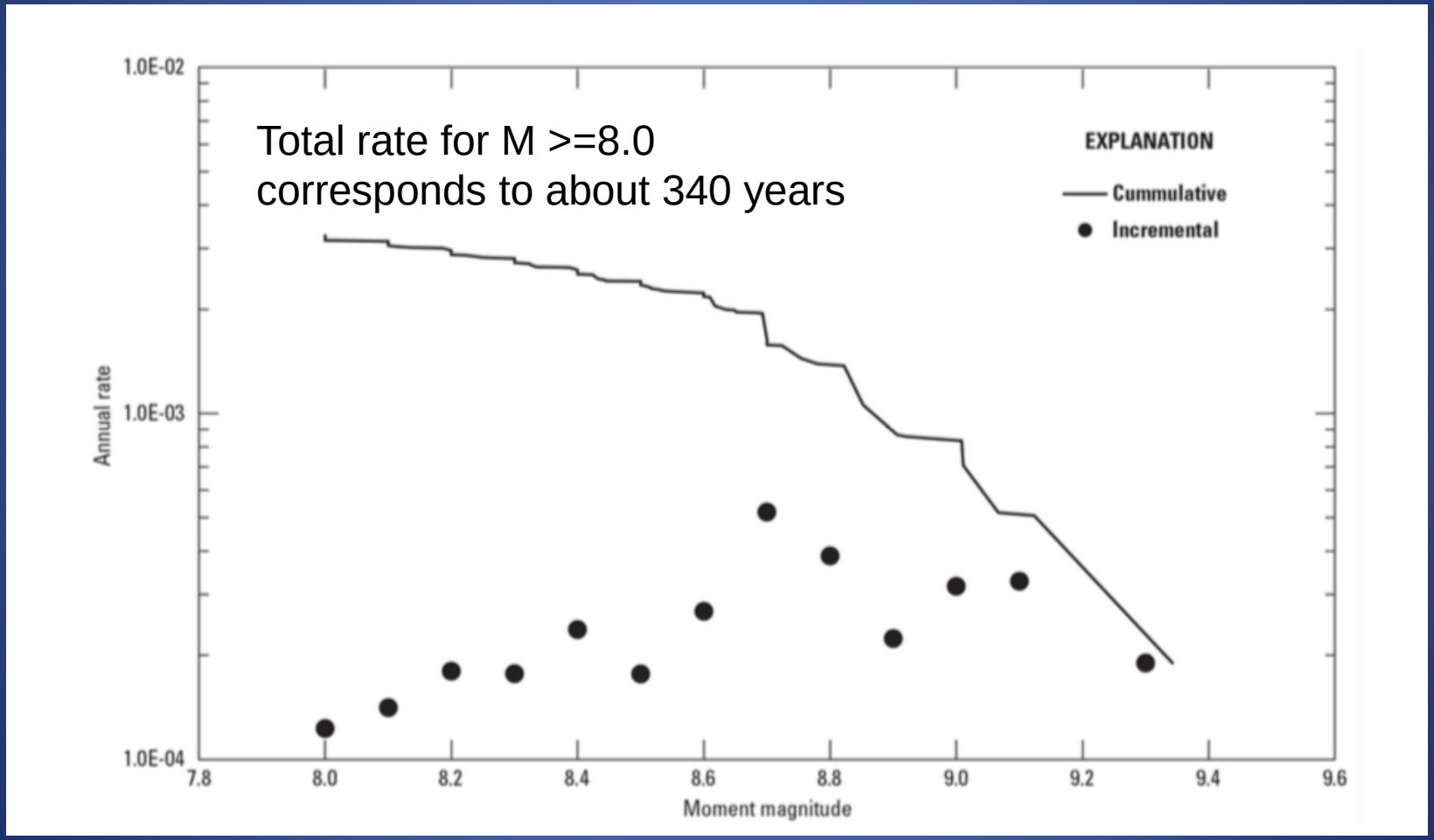
Cumulative rate of earthquakes on CSZ from the weighted models



From USGS OFR 2014-1091

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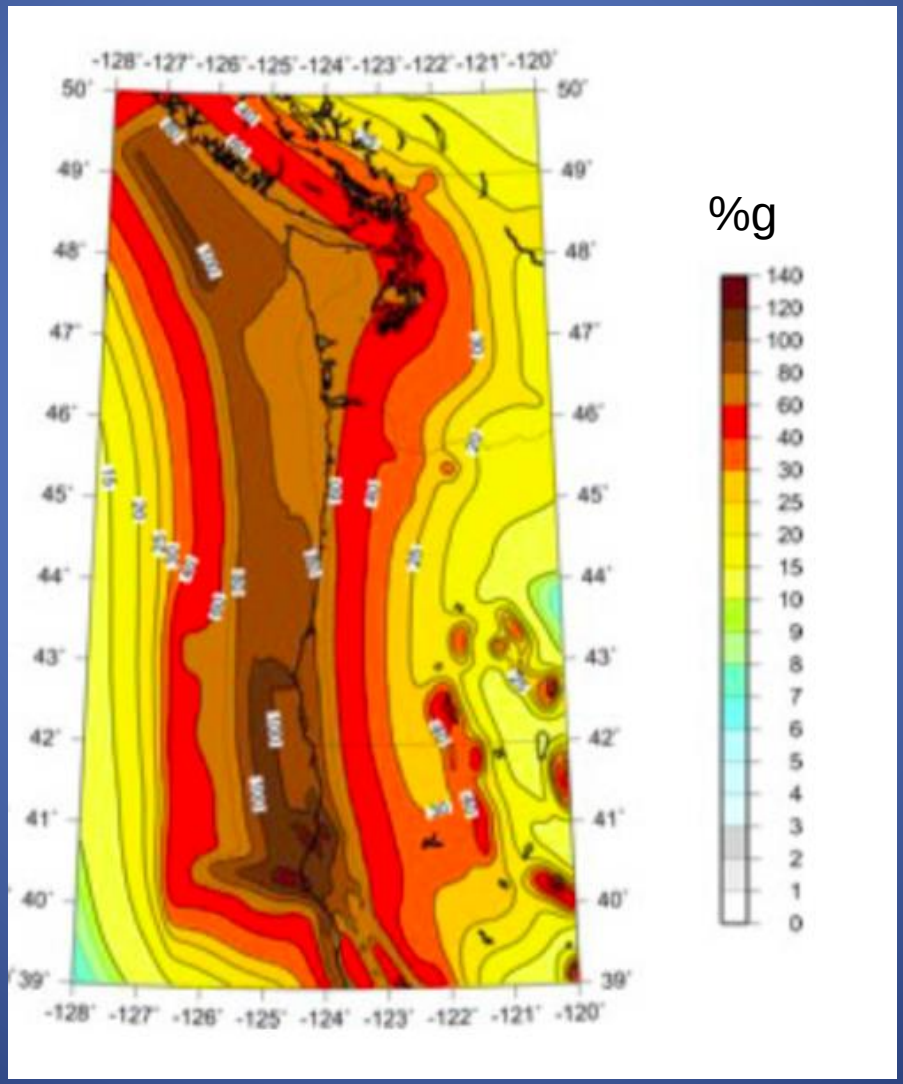
Peak Ground Acceleration (%g) with 2% chance of being exceeded in 50 years; rock sites (2008)



From
USGS OFR 2014-1091

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USGS is in planning stage of developing the 2023 update of the National Seismic Hazard Model (Mark Petersen, project chief)

- Planning a set of virtual workshops on Cascadia subduction zone, crustal faults in WA and OR, and ground motion models (NGA subduction and M9 sedimentary basin amplification)
- Evaluate any new findings or interpretations that could modify the CSZ logic trees
- Talks will be pre-recorded and available for viewing before workshop, so that workshop is dominated by discussions
- CSZ virtual workshop in late 2020 or early 2021; welcome participation of scientists, engineers, members of OSSPAC, DOGAMI, WADNR, and other agencies

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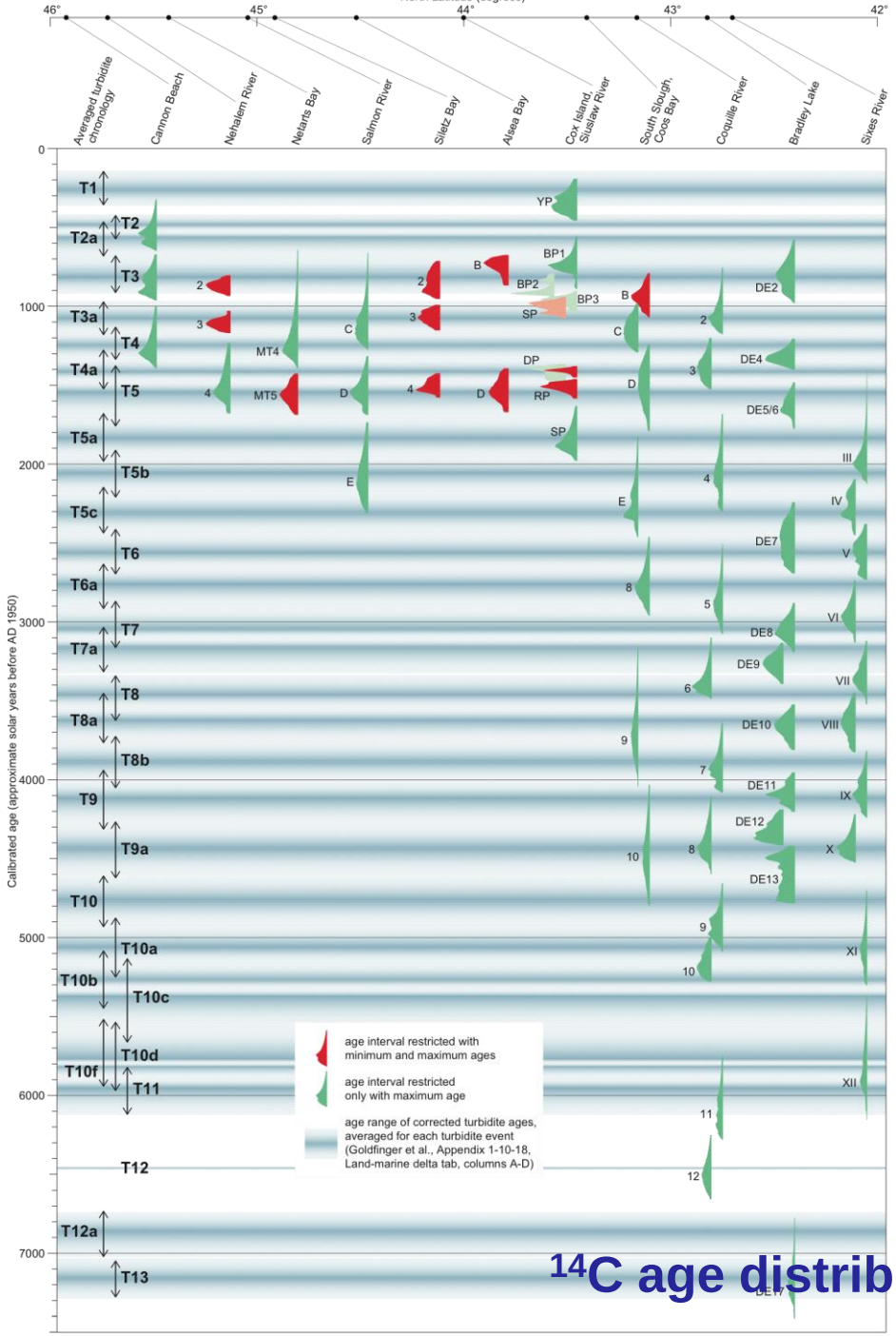
N

S

Green and red age distributions from on land data (Atwater, Hemphill-Haley, Kelsey, Witter, Nelson and others)

Dark blue horizontal lines are earthquake dates from marine Turbidites (Goldfinger et al. 2012)

Slide from Alan Nelson



^{14}C age distributions

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