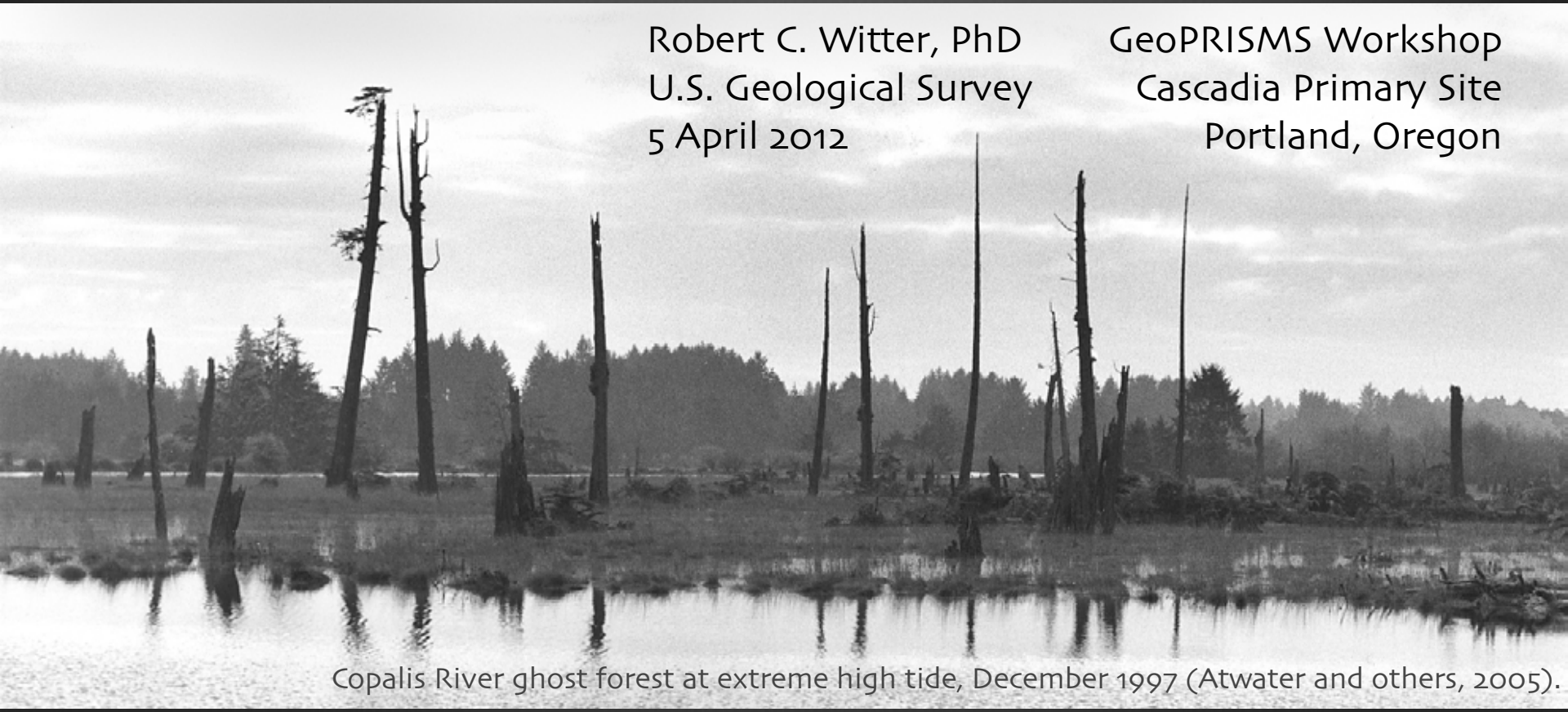
Paleoseismic History of Cascadia

from Onshore and Offshore Evidence

Robert C. Witter, PhD
U.S. Geological Survey
5 April 2012

GeoPRISMS Workshop
Cascadia Primary Site
Portland, Oregon

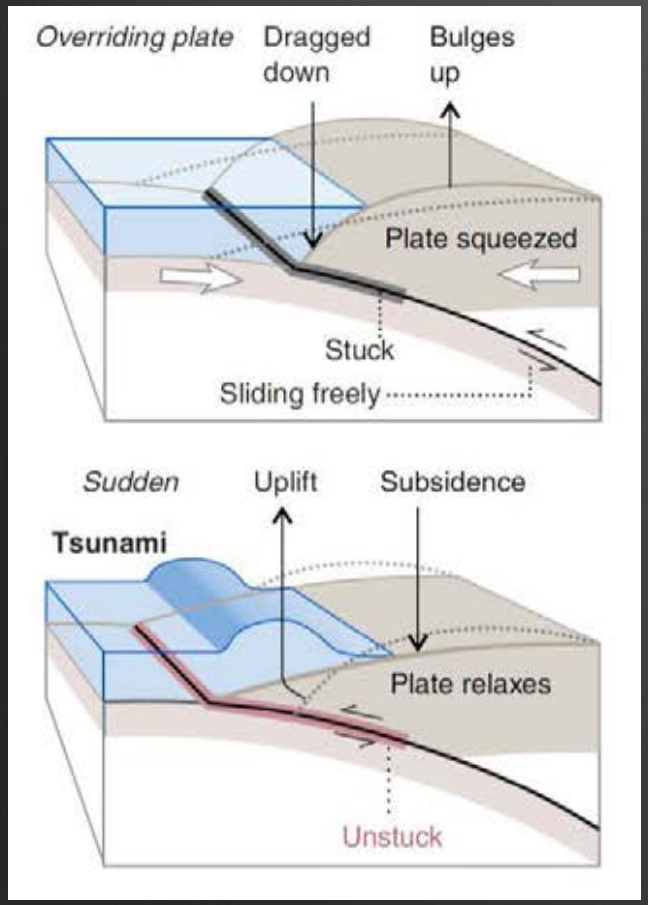


Copalis River ghost forest at extreme high tide, December 1997 (Atwater and others, 2005).

NOTE: This revised presentation was first delivered during a talk on April 5, 2012, at the GeoPRISMS workshop in Portland, Oregon

What can paleoseismology tell us?

GeoPRISMS SCD key questions:



Atwater and others, 2005

1. What controls the size, location and frequency of great megathrust earthquakes?
   - How is this related to the variability of slip behavior?
2. How does crustal deformation evolve over multiple megathrust earthquake cycles?

Talk outline

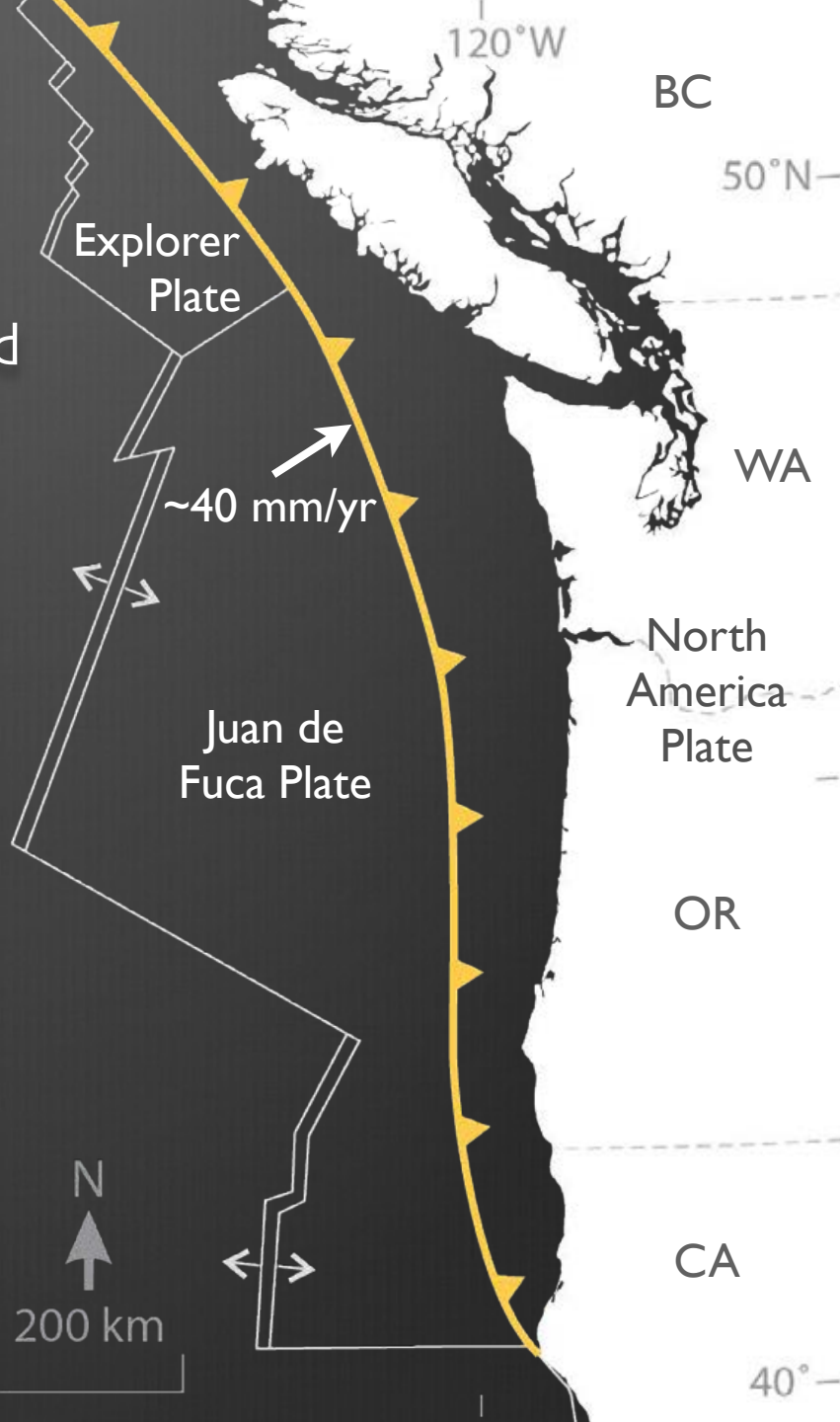
Summary of the paleoseismic record

Onshore and offshore evidence

- Drowned lowlands
- Sand sheets
- Turbidity currents

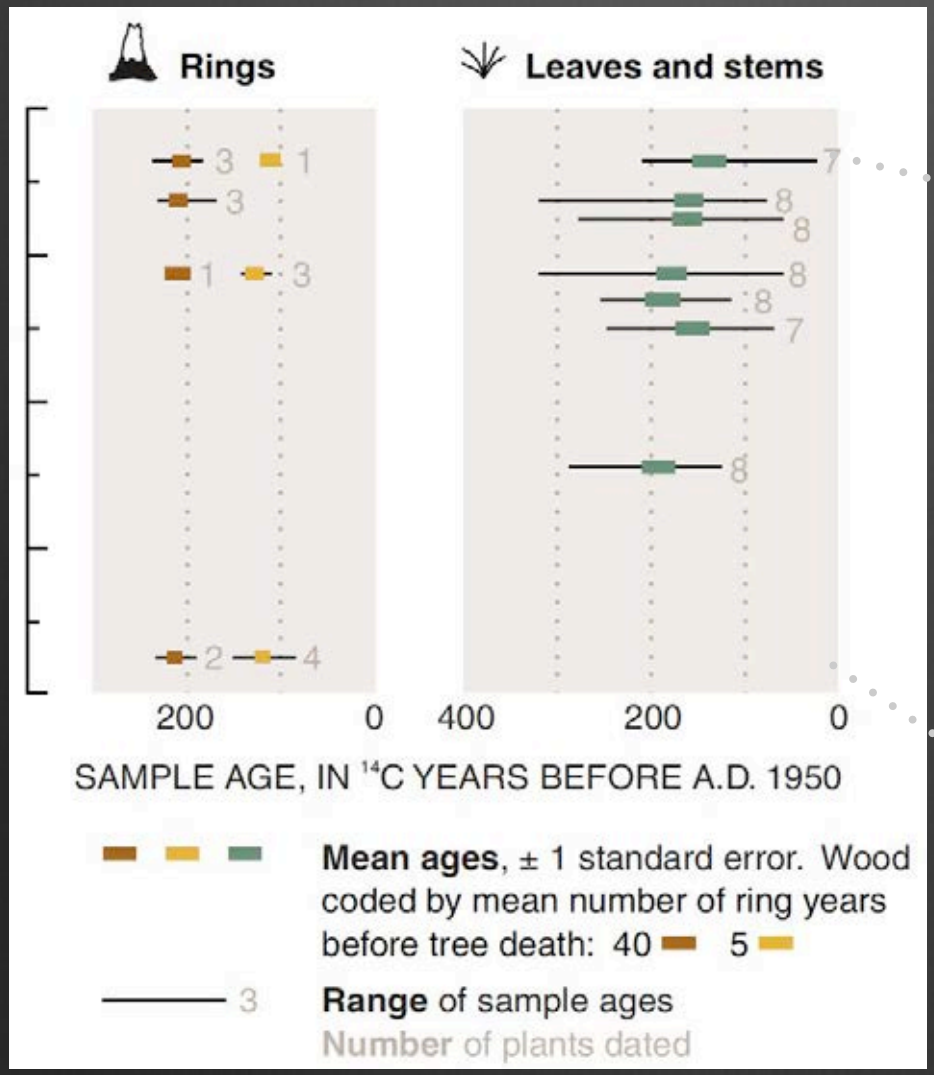
Recent breakthroughs

Outstanding questions

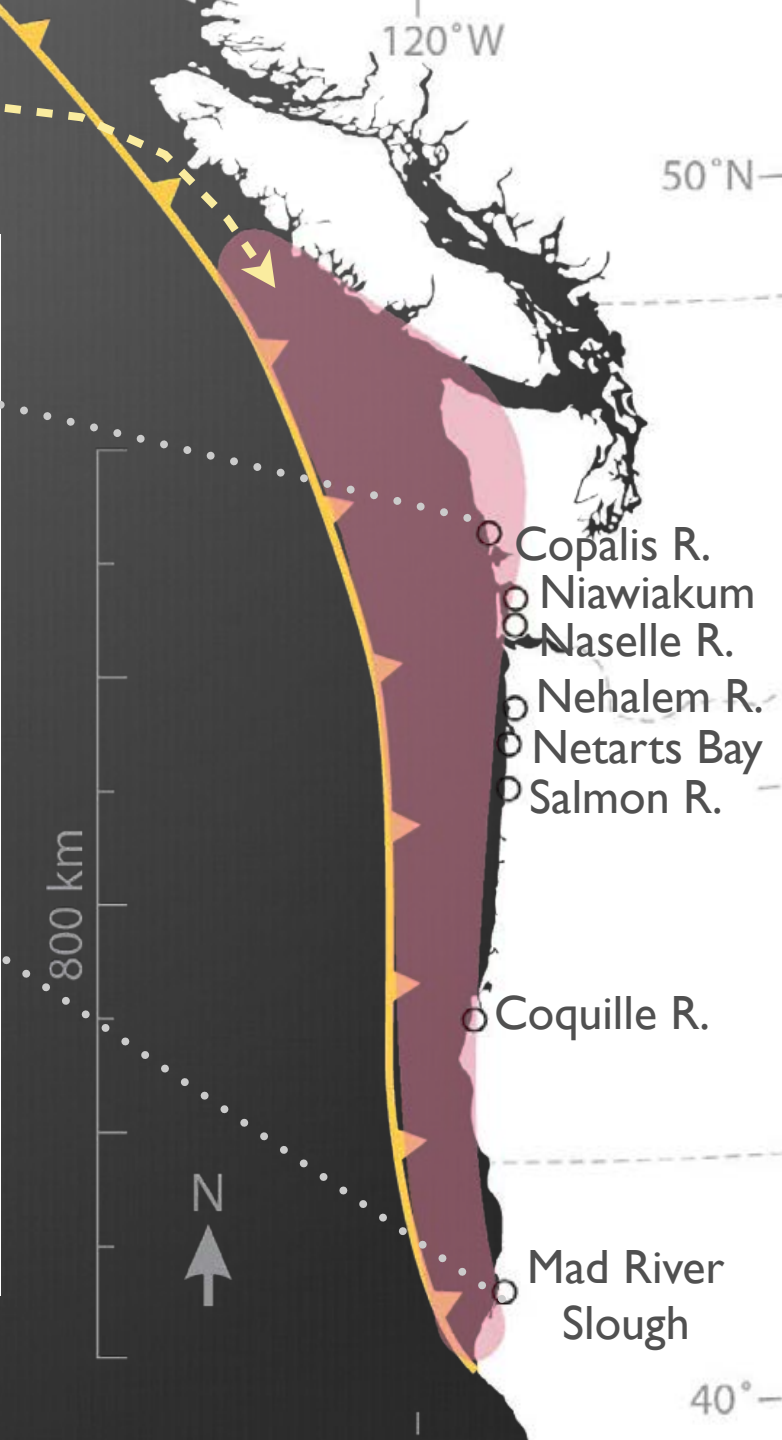


Dinner sausage?

Early tests of earthquake size failed

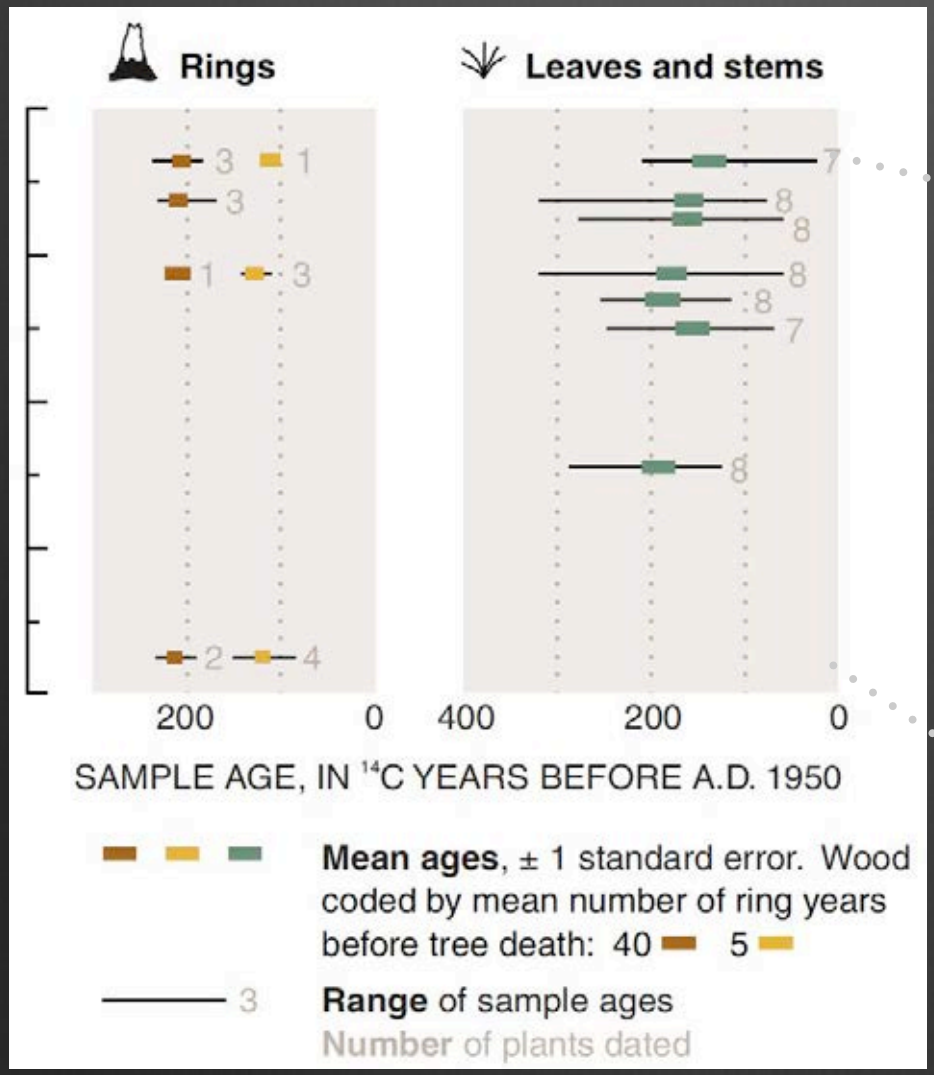


From Atwater and others, 2005
Citing Atwater and others, 1991;
Nelson and others, 1995



… or breakfast links?

Time of earthquake placed within decades of 1700



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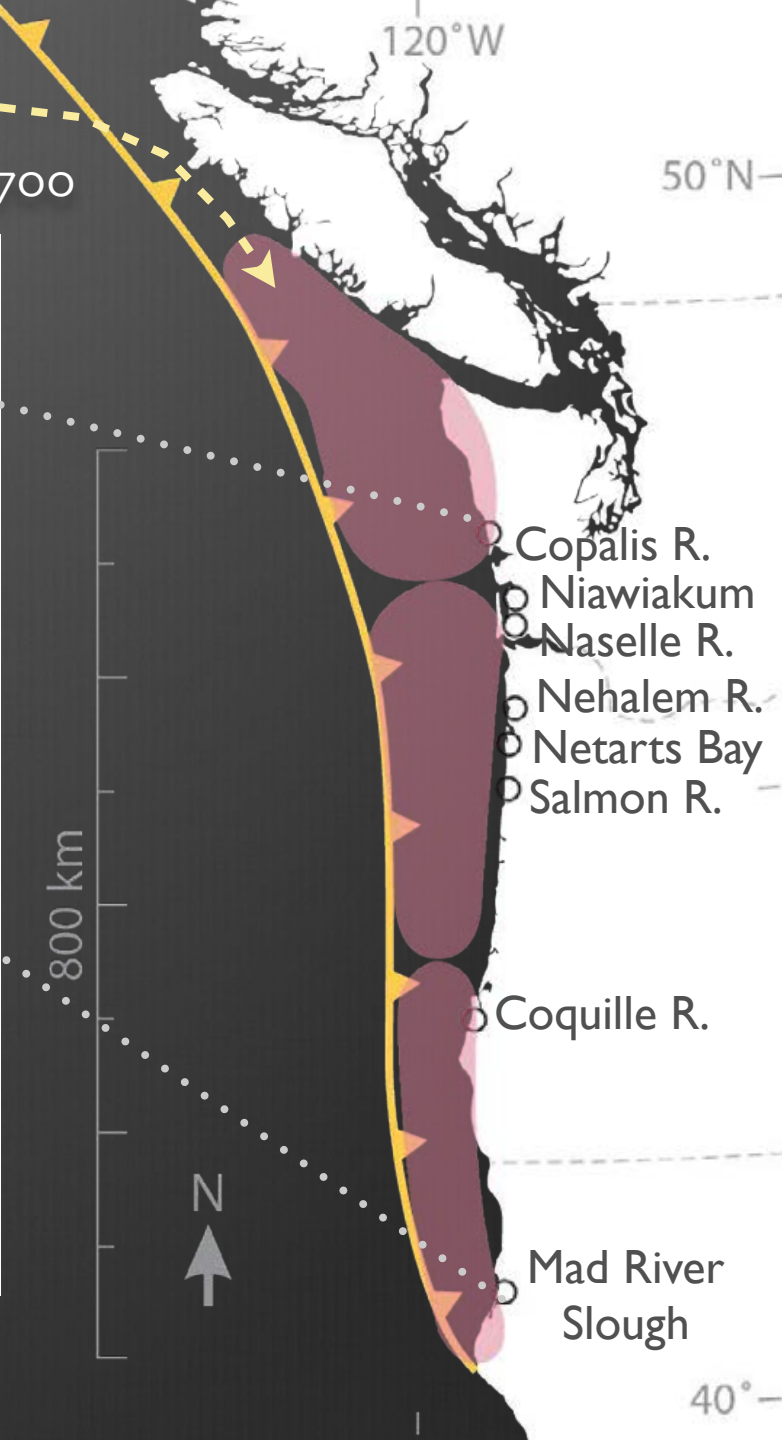
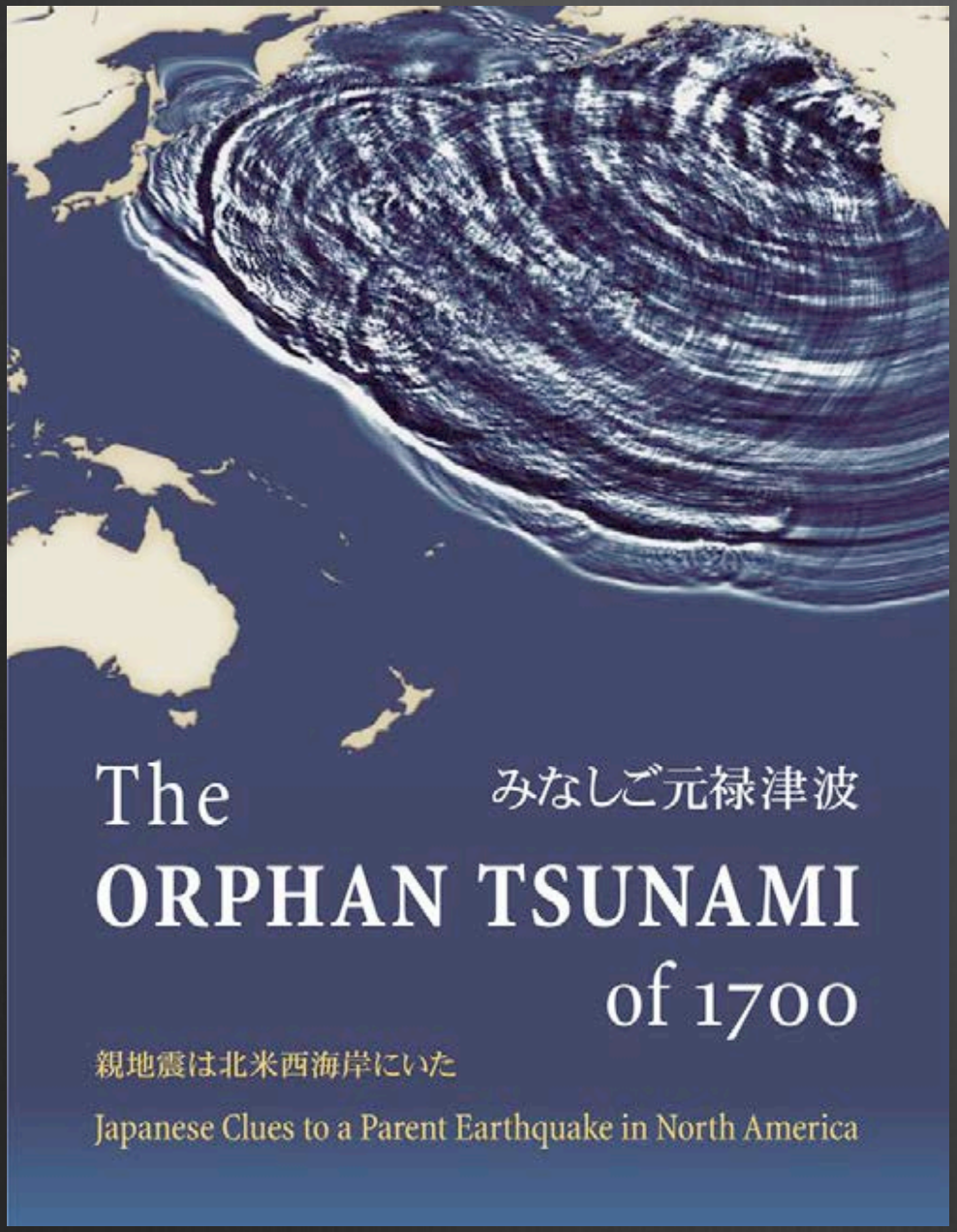
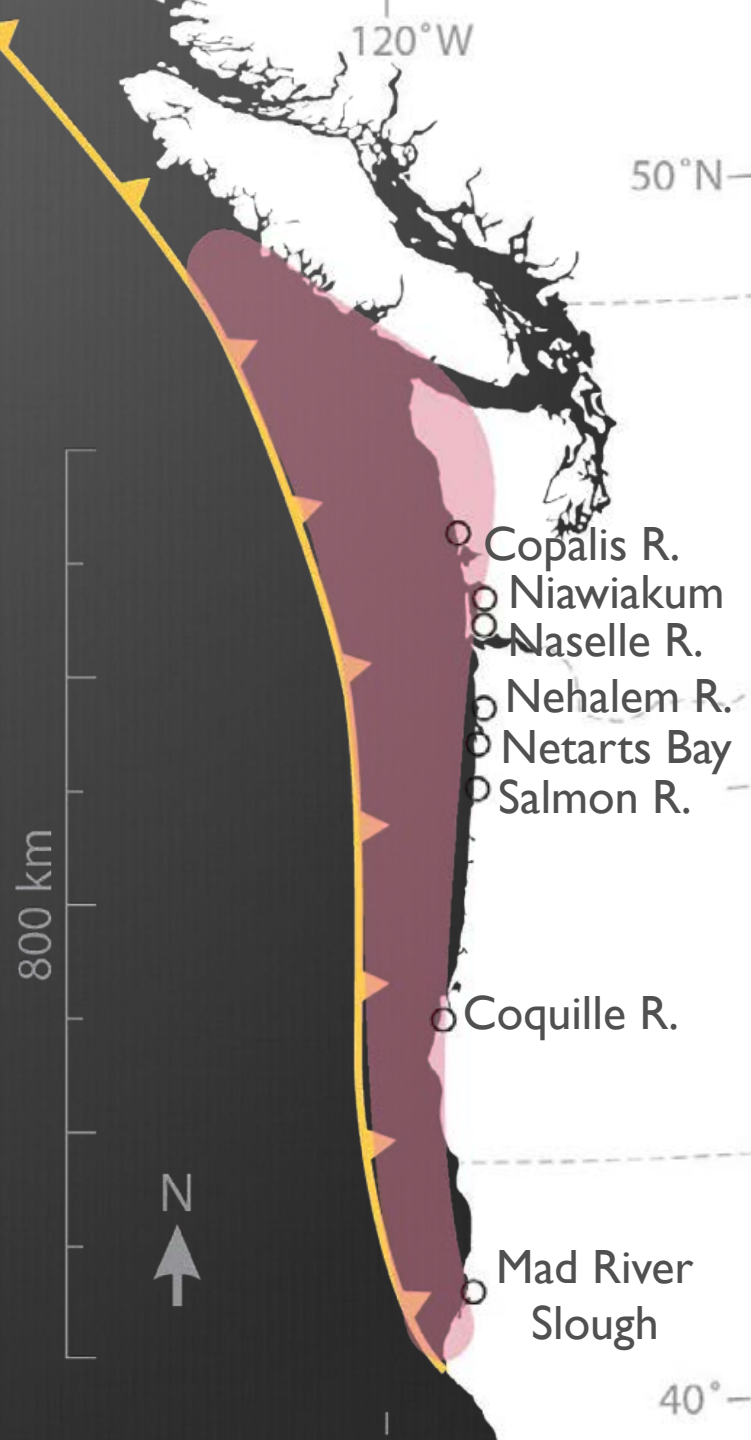




Satake and others, 1996; 2003;
Atwater and others, 2005



Onland evidence

Vancouver Island sites [3-6 earthquakes]

>300 yr average recurrence interval

Length of record spans **<3,000** yrs

Southwestern Washington estuaries [7-9]

500-530 yr average over **<5,000** yrs

Northern and central Oregon coast [4-6]

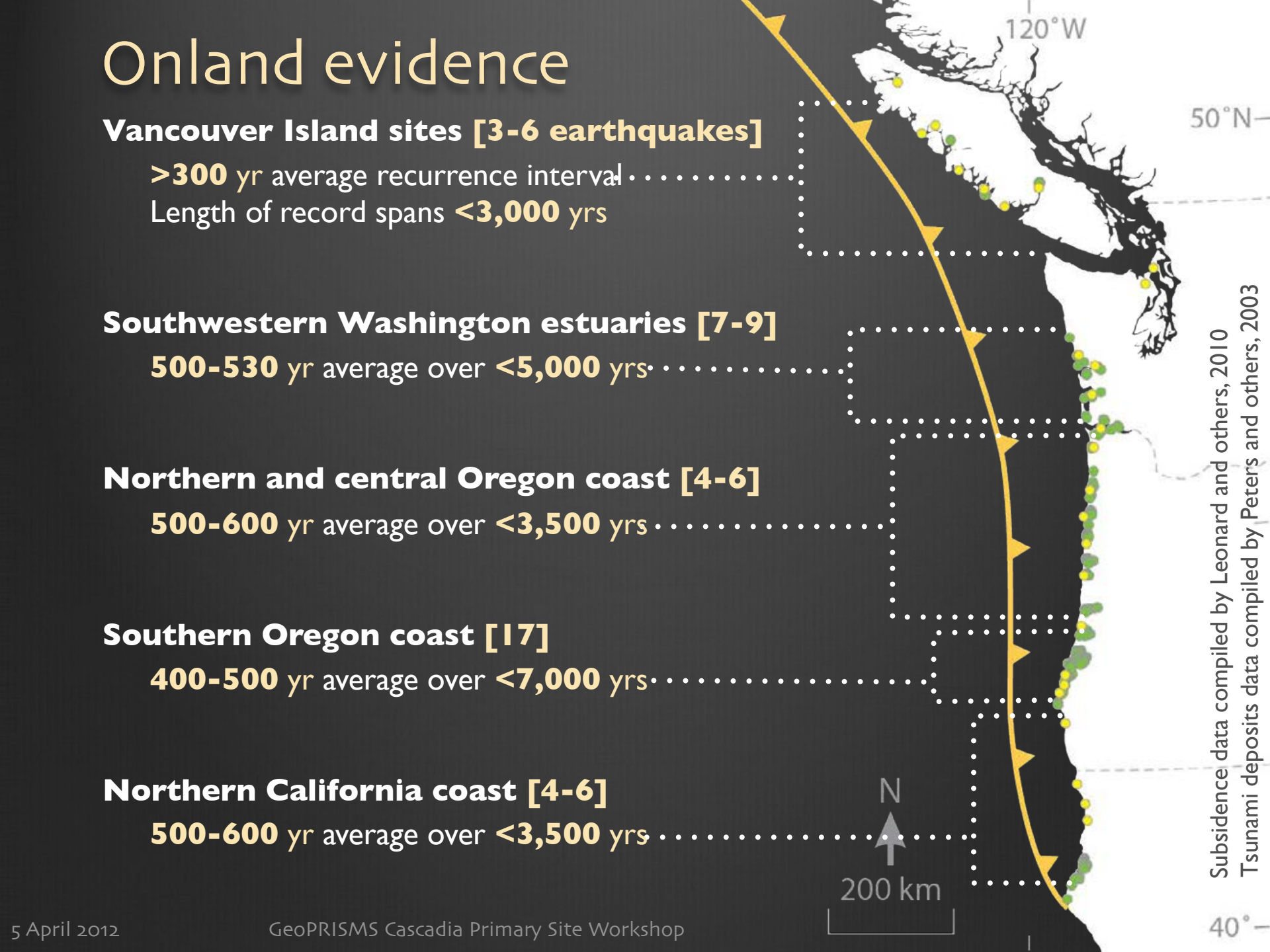
500-600 yr average over **<3,500** yrs

Southern Oregon coast [17]

400-500 yr average over **<7,000** yrs

Northern California coast [4-6]

500-600 yr average over **<3,500** yrs



Offshore evidence

Washington margin [19 turbidites]

500-530 yr average over **~10,000** yrs
(Goldfinger and others, 2012)

Northern Oregon margin [23]

410-500 yr average over **~10,000** yrs

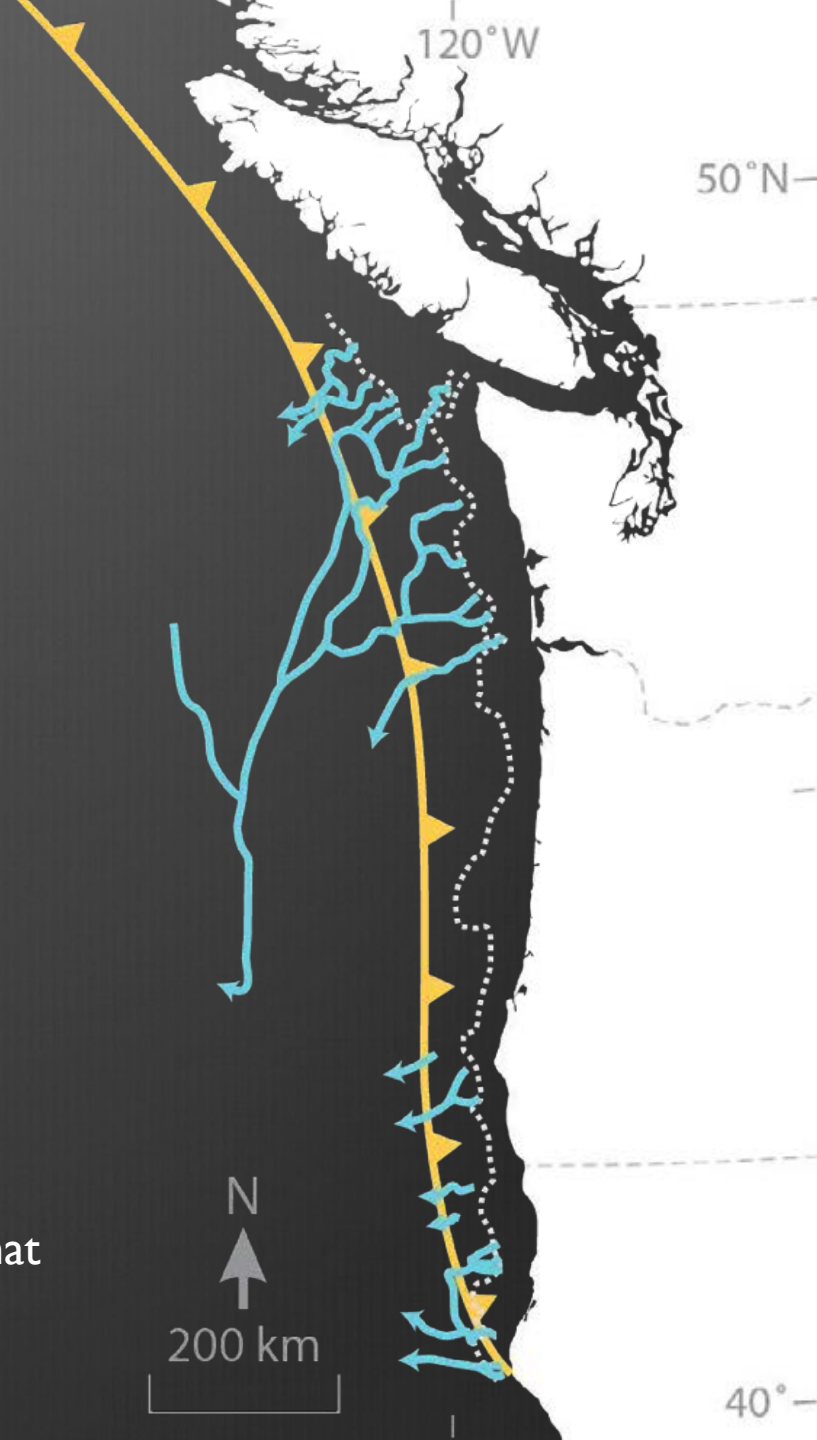
Central Oregon margin [32]*

300-380 yr average over **~10,000** yrs

Southern Cascadia margin [42]*

220-240 yr average over **~10,000** yrs

* Recurrence intervals based on the inference that megathrust earthquakes produced all turbidites



Evidence in the north

Offshore southern Vancouver Island

>300 yr average recurrence interval

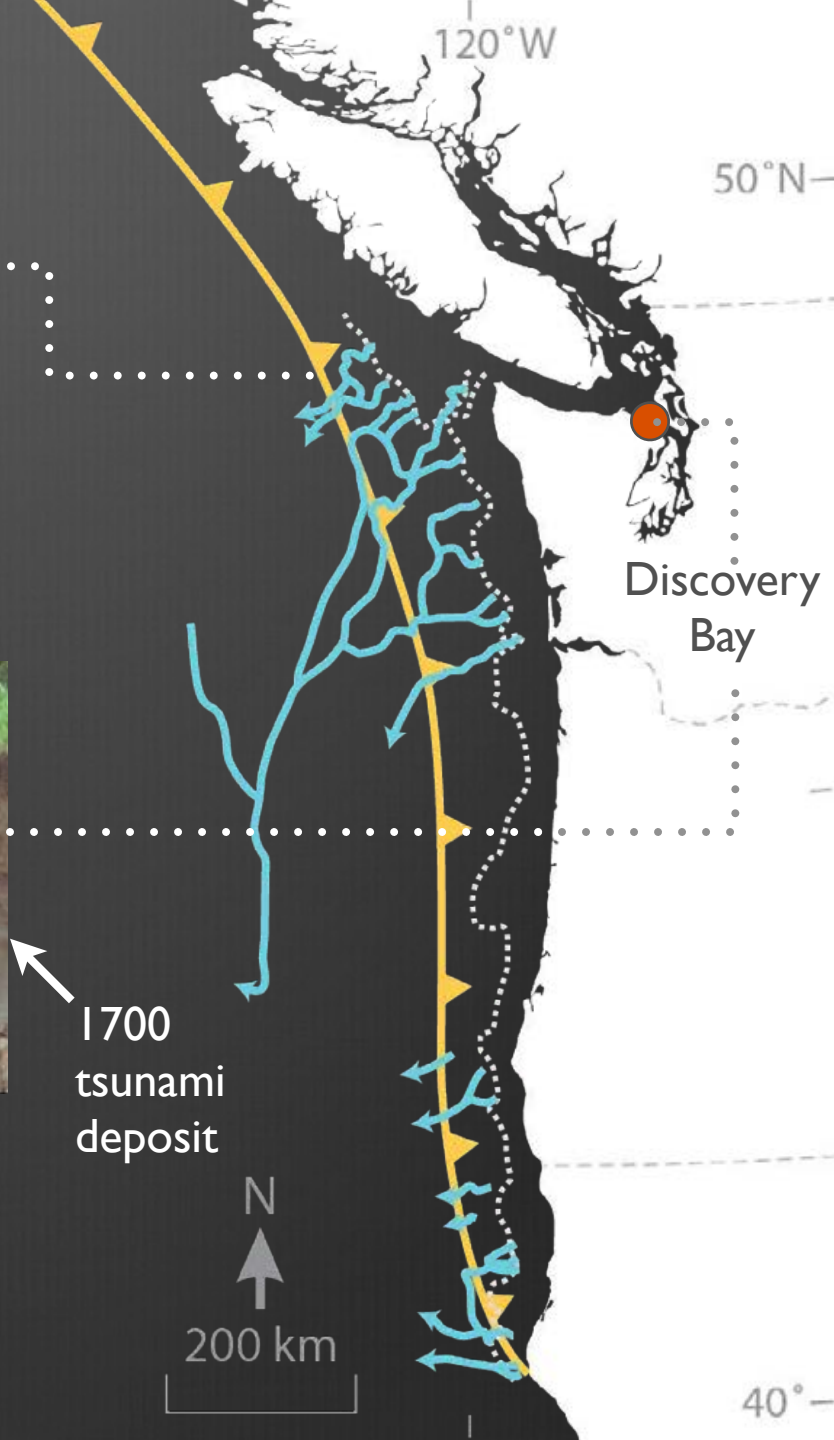
Length of record spans **<3,000** yrs

(Atwater and Griggs, 2012)

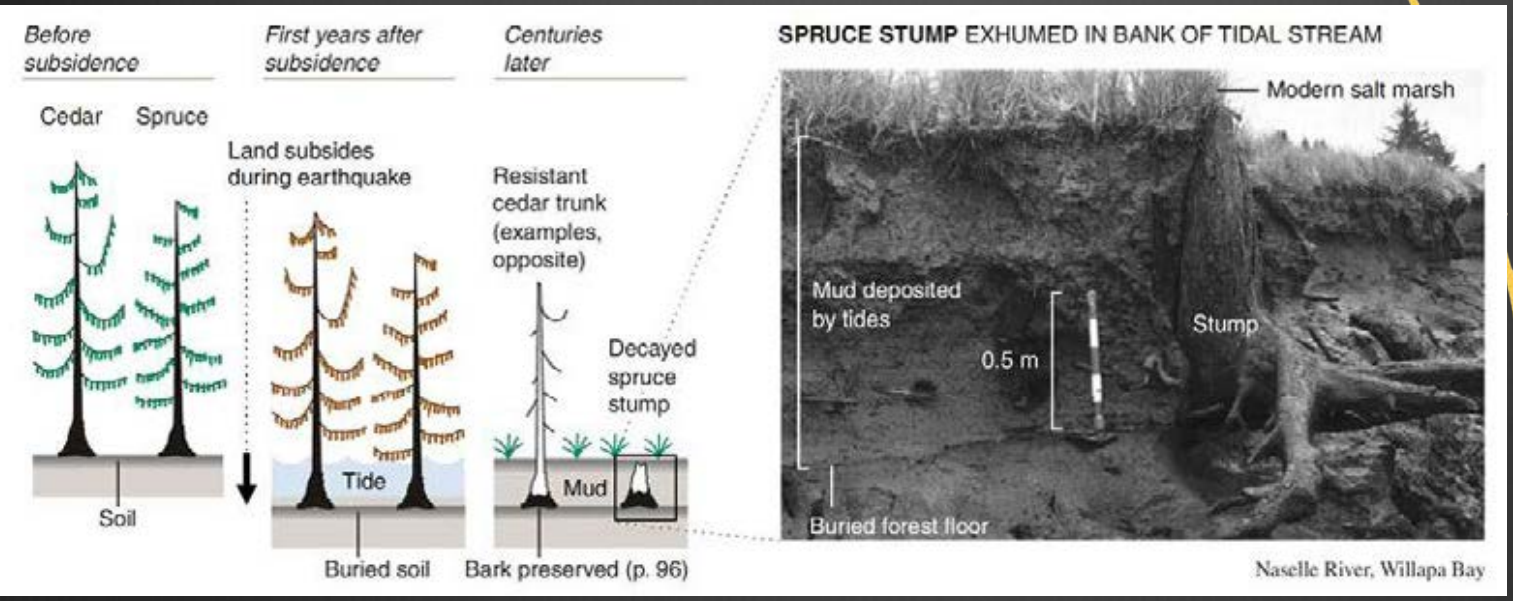
300 yr average at Discovery Bay

(Williams and others, 2005)

1700 tsunami deposit

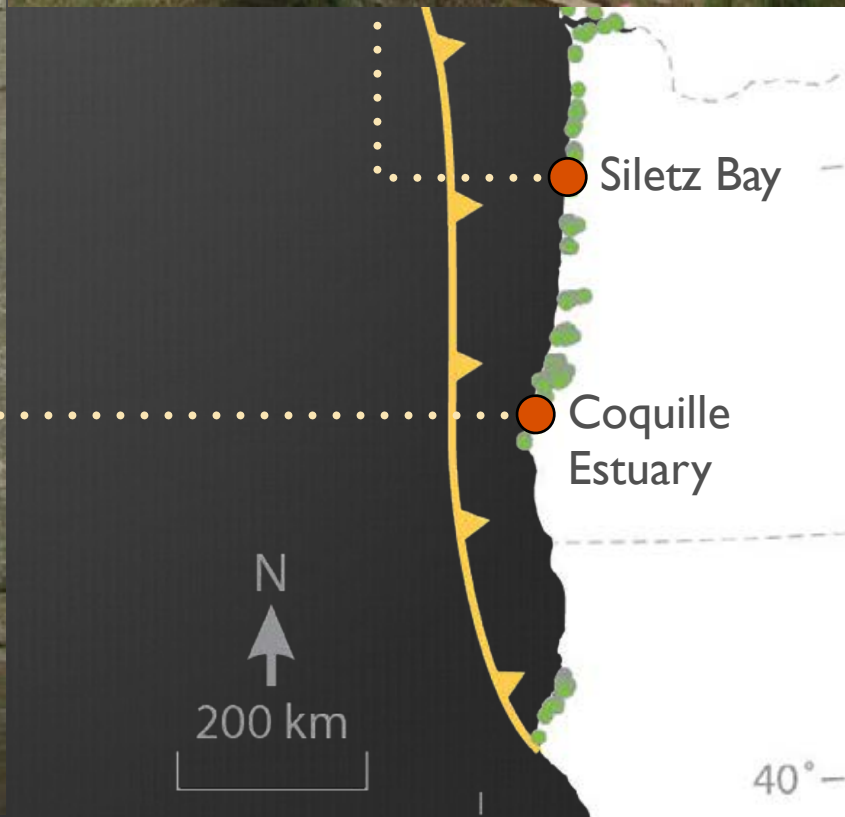


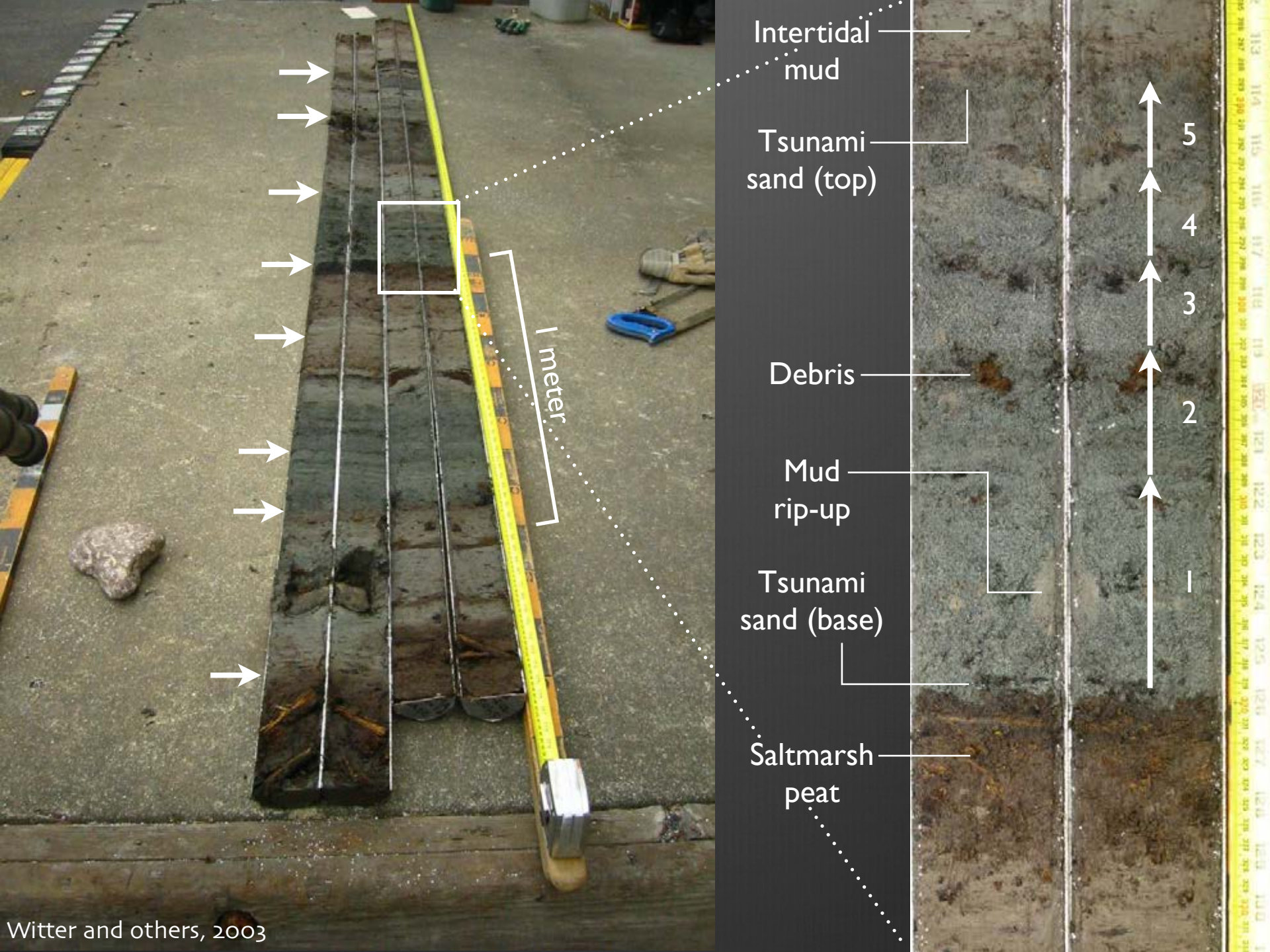
Coseismic subsidence



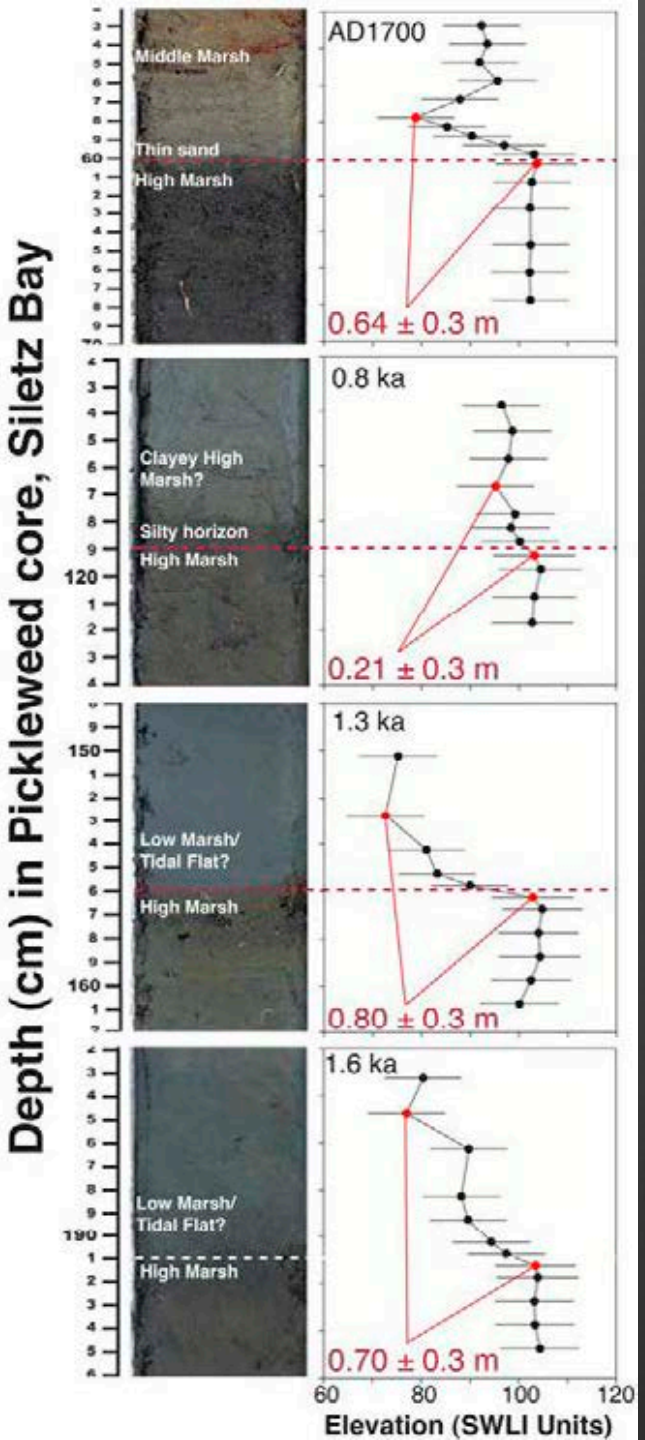
Atwater and others, 2005

Witter and others, 2003



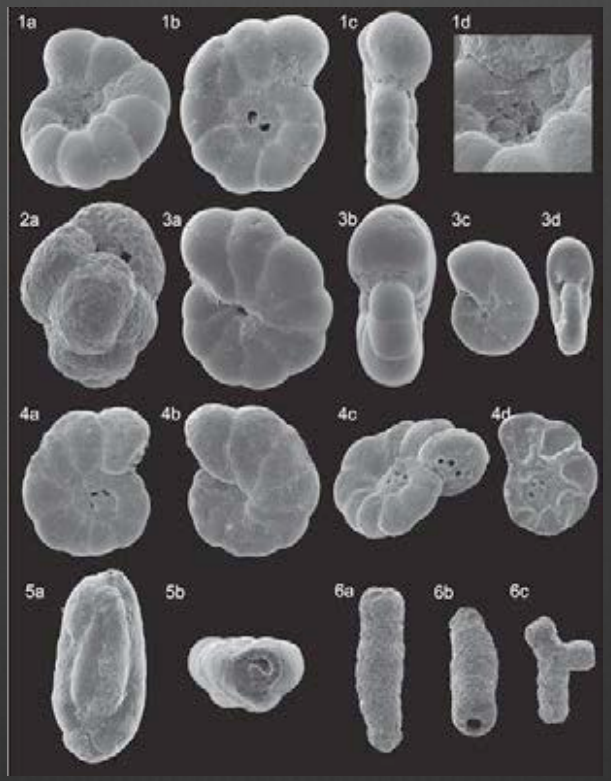


Witter and others, 2003



Did past earthquakes vary in size?

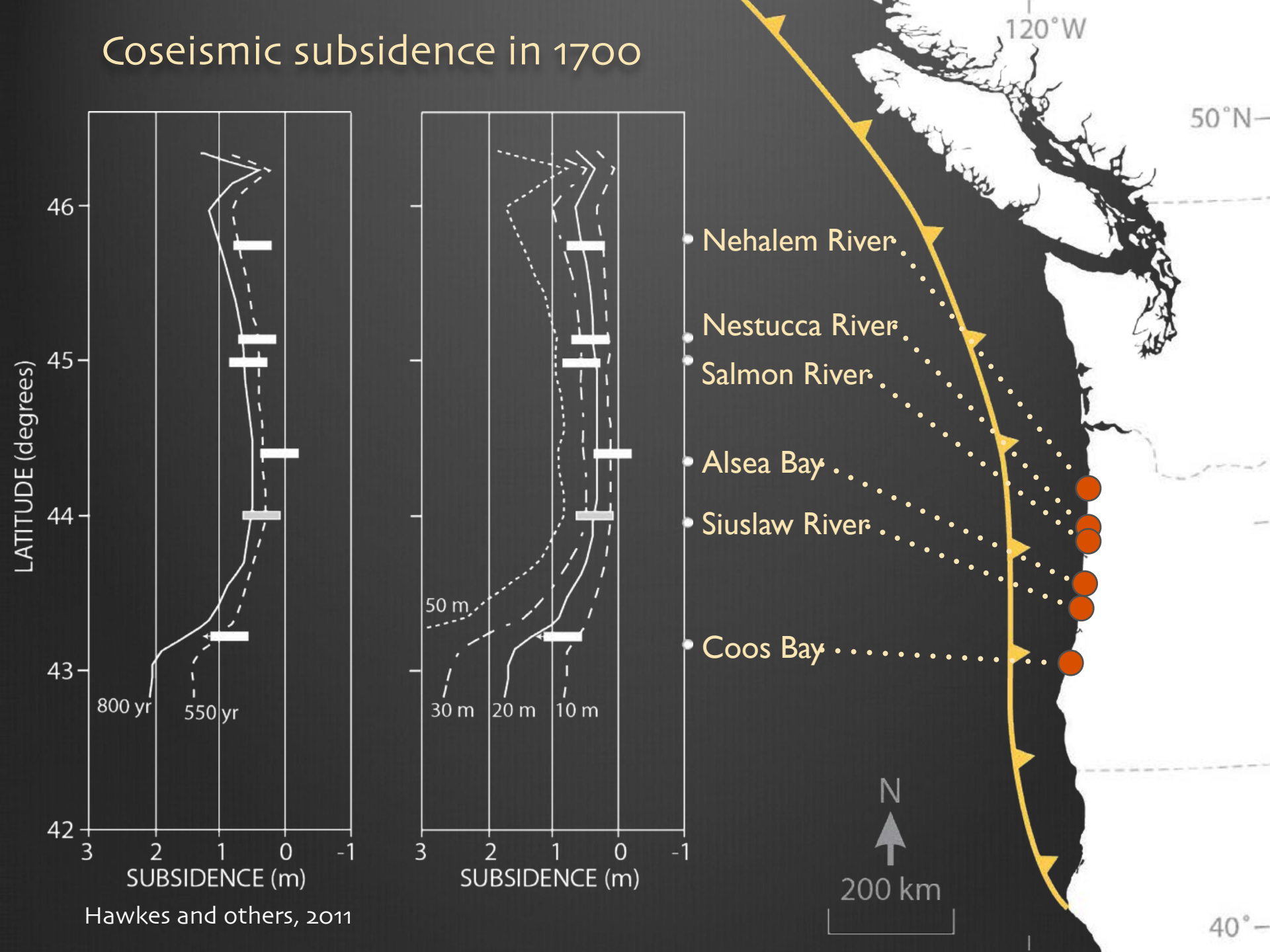
Fossil foraminifera



Horton and Edwards, 2006

Engelhart and others unpublished data

Coseismic subsidence in 1700

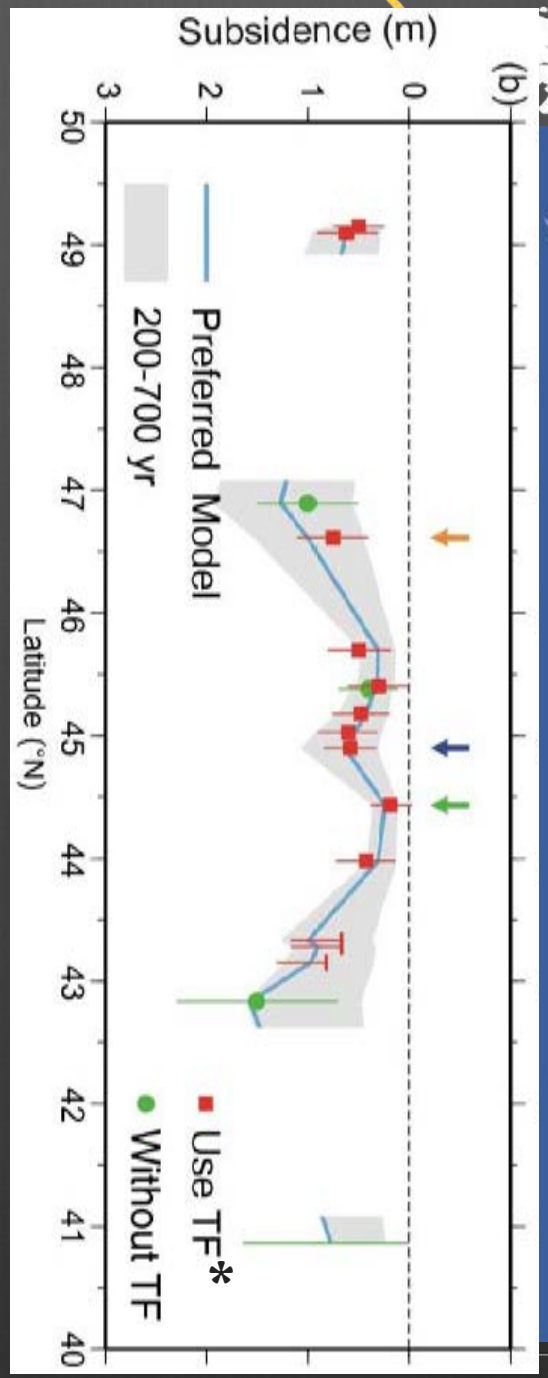


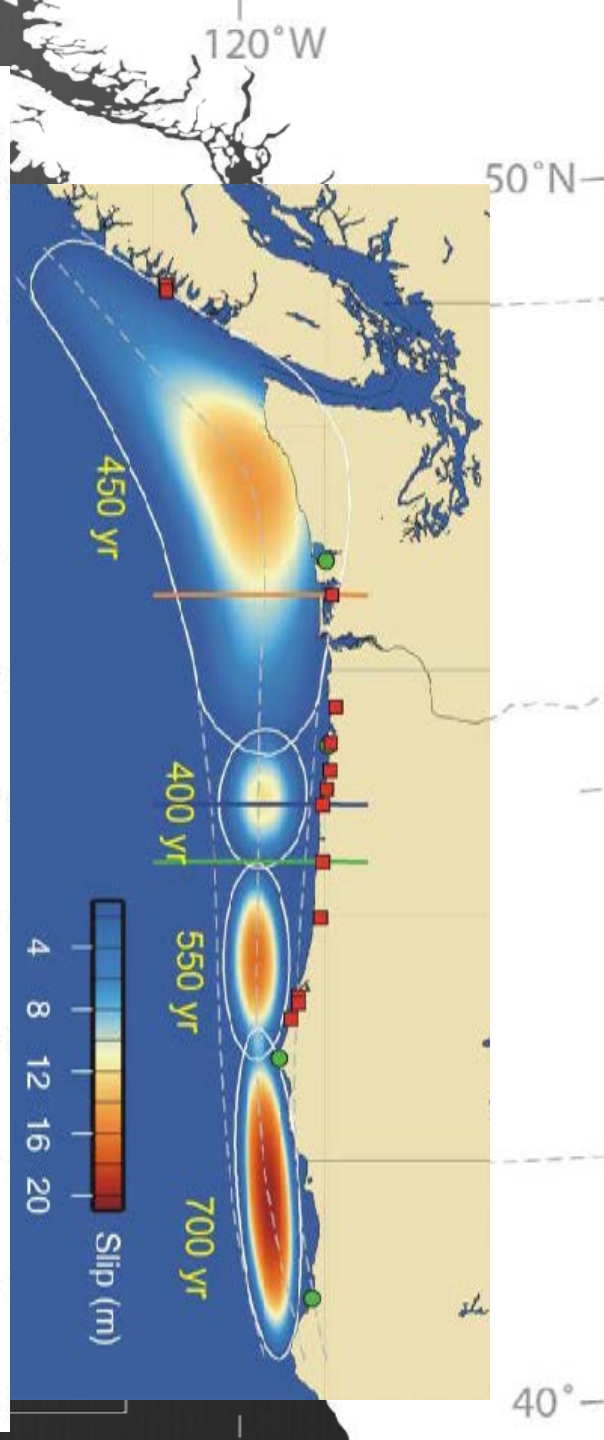
Hawkes and others, 2011

New rupture model for 1700 earthquake

Reveals details of slip distribution pattern

Highlights possible rupture barriers

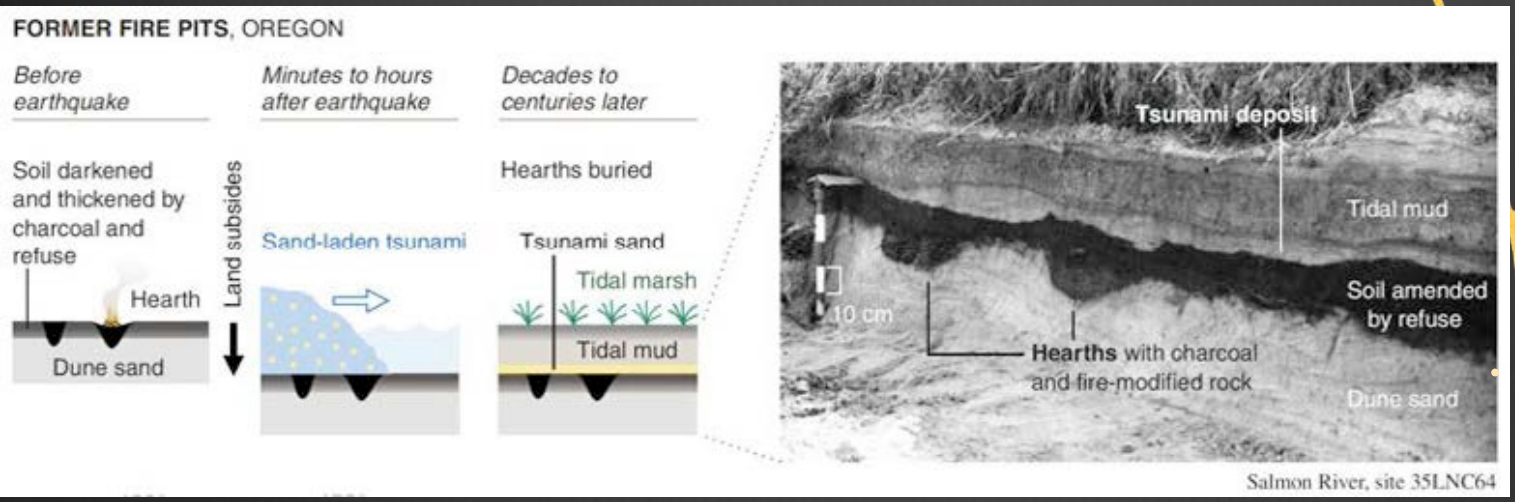




Wang and others, 2011
Horton and others, 2012
GeoPRISMS white paper

* TF - Transfer function. Refer to Wang and others (2011) for details.

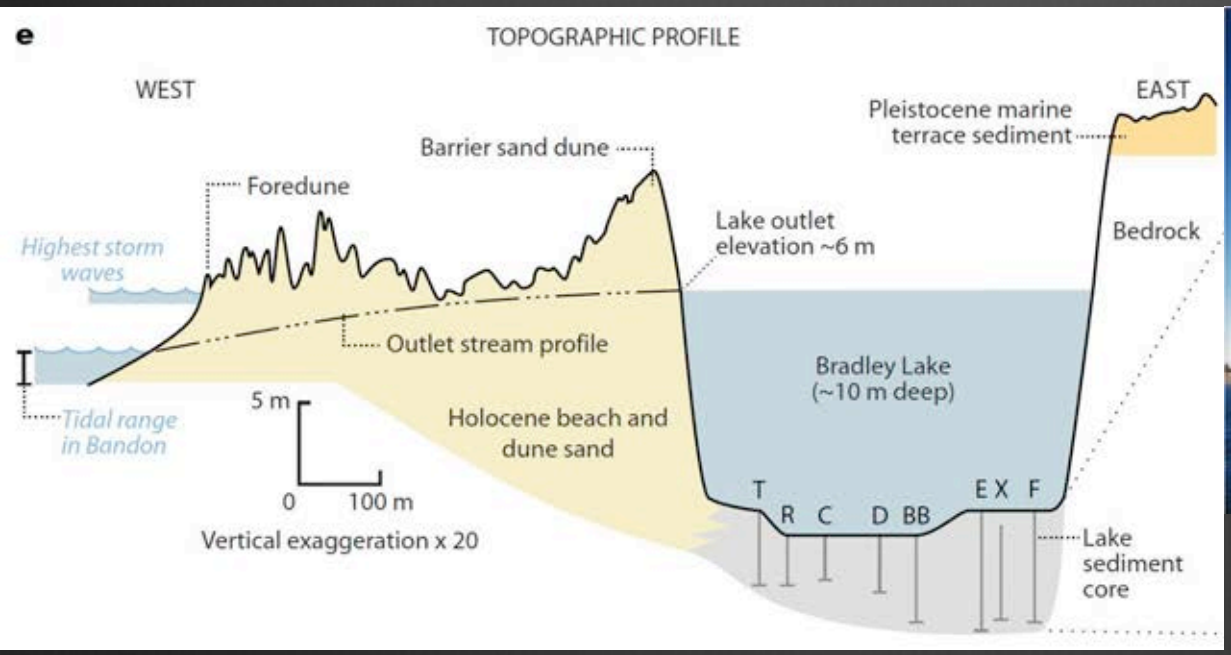
Tsunami deposits



Atwater and others, 2005

Bradley Lake, Oregon

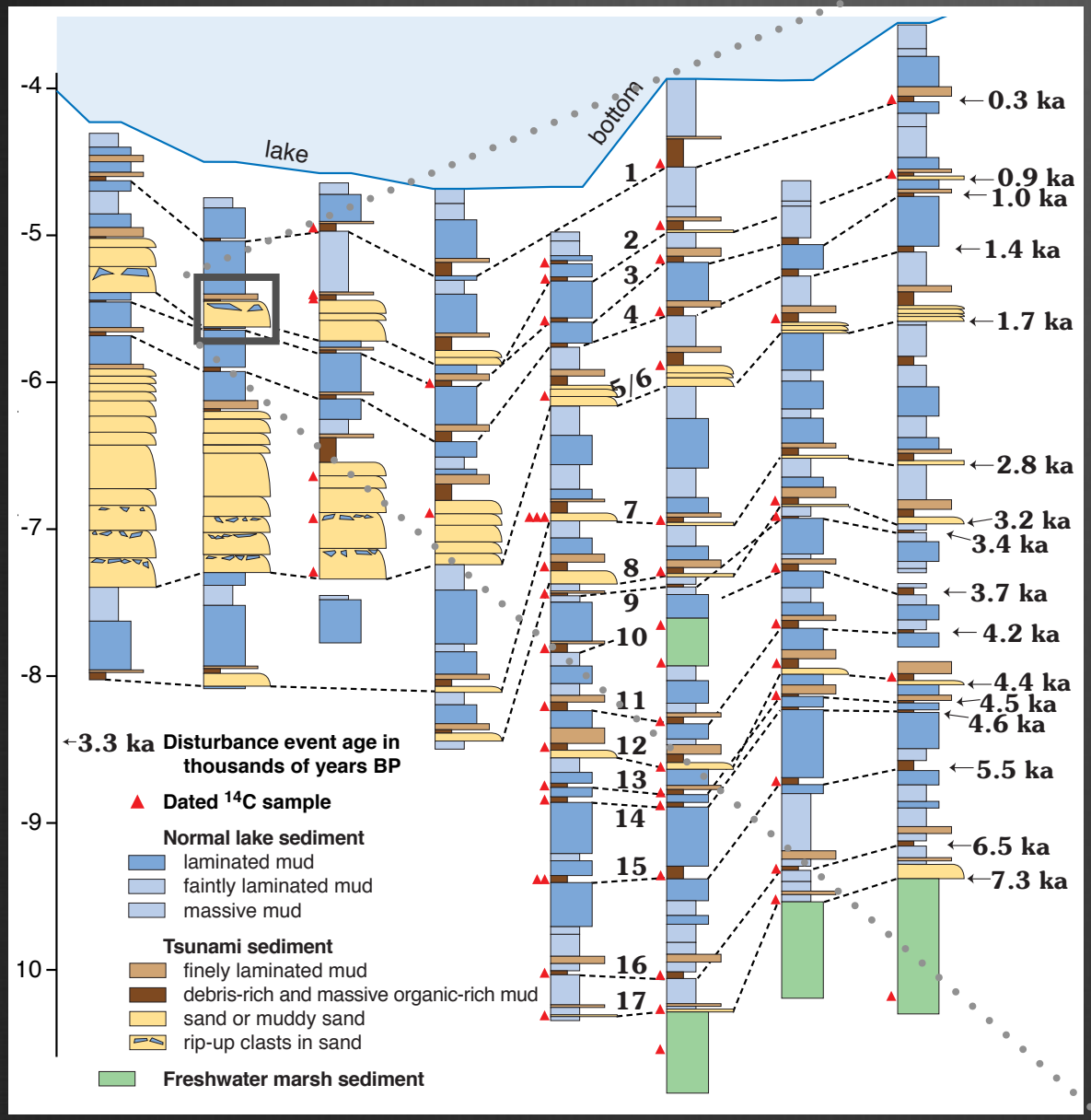
4,600-yr record of tsunami inundation

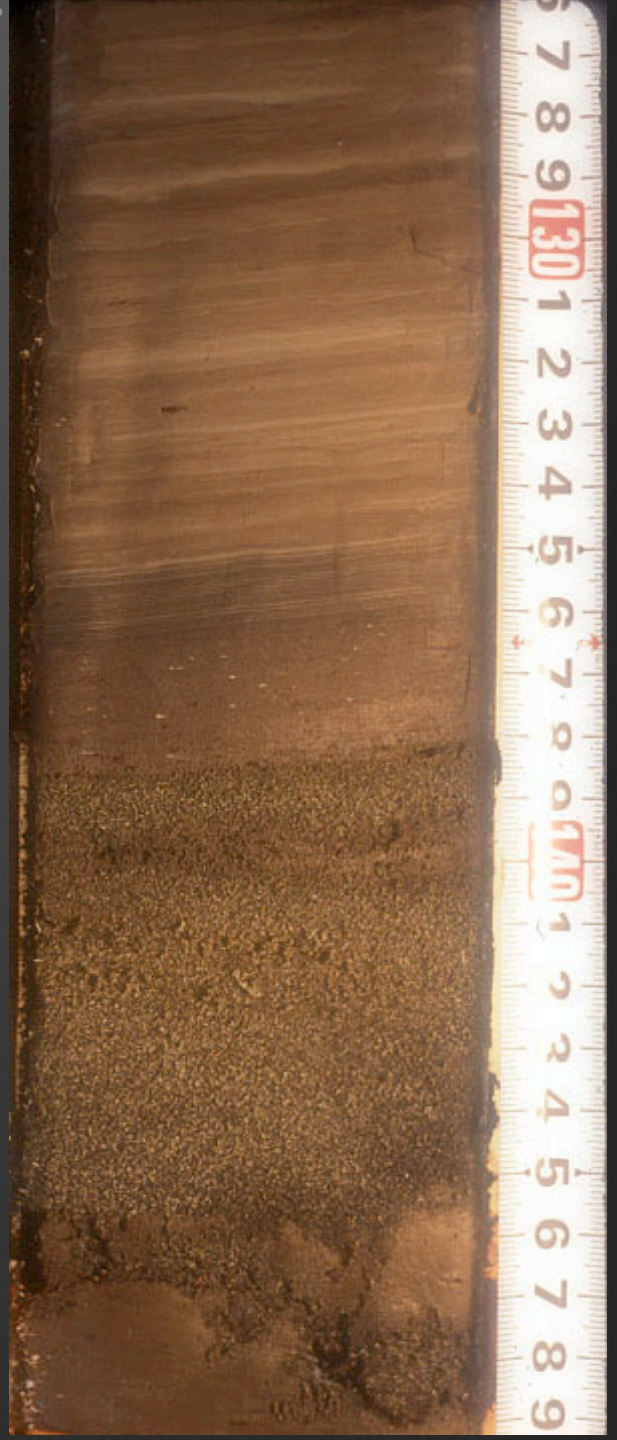


Witter and others, 2012;
after Kelsey and others, 2005

12 Cascadia tsunami deposits in 4,600 yrs

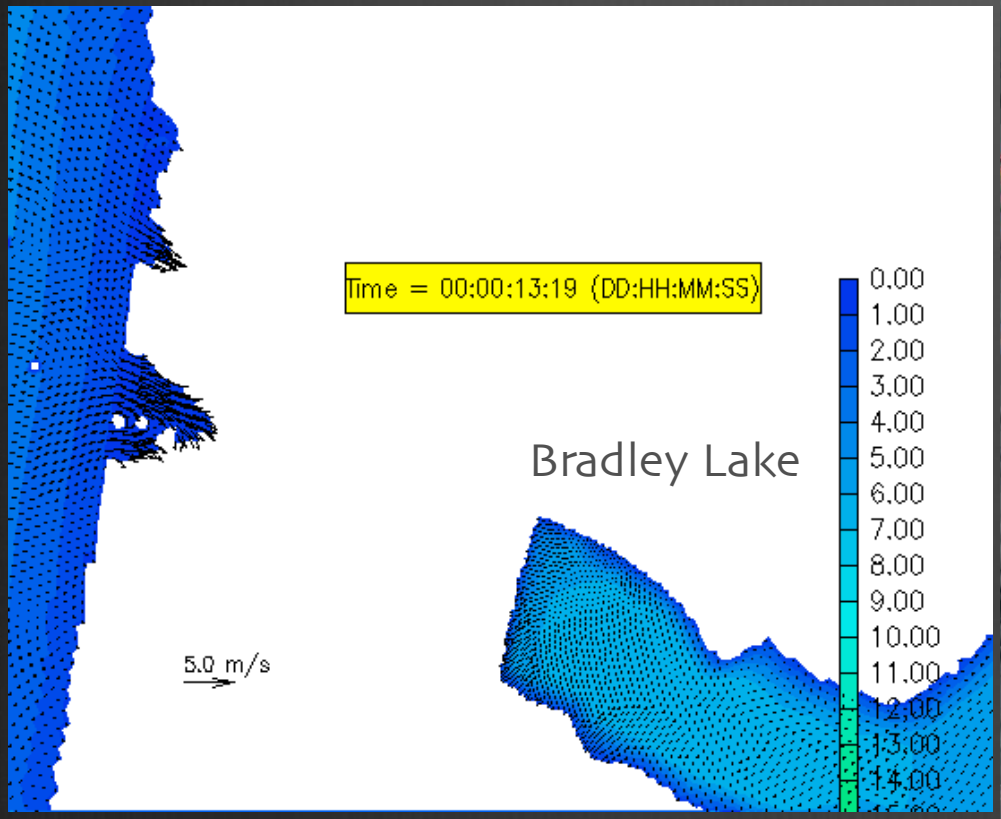
tsunamis penetrated lake outlet dammed by foredunes





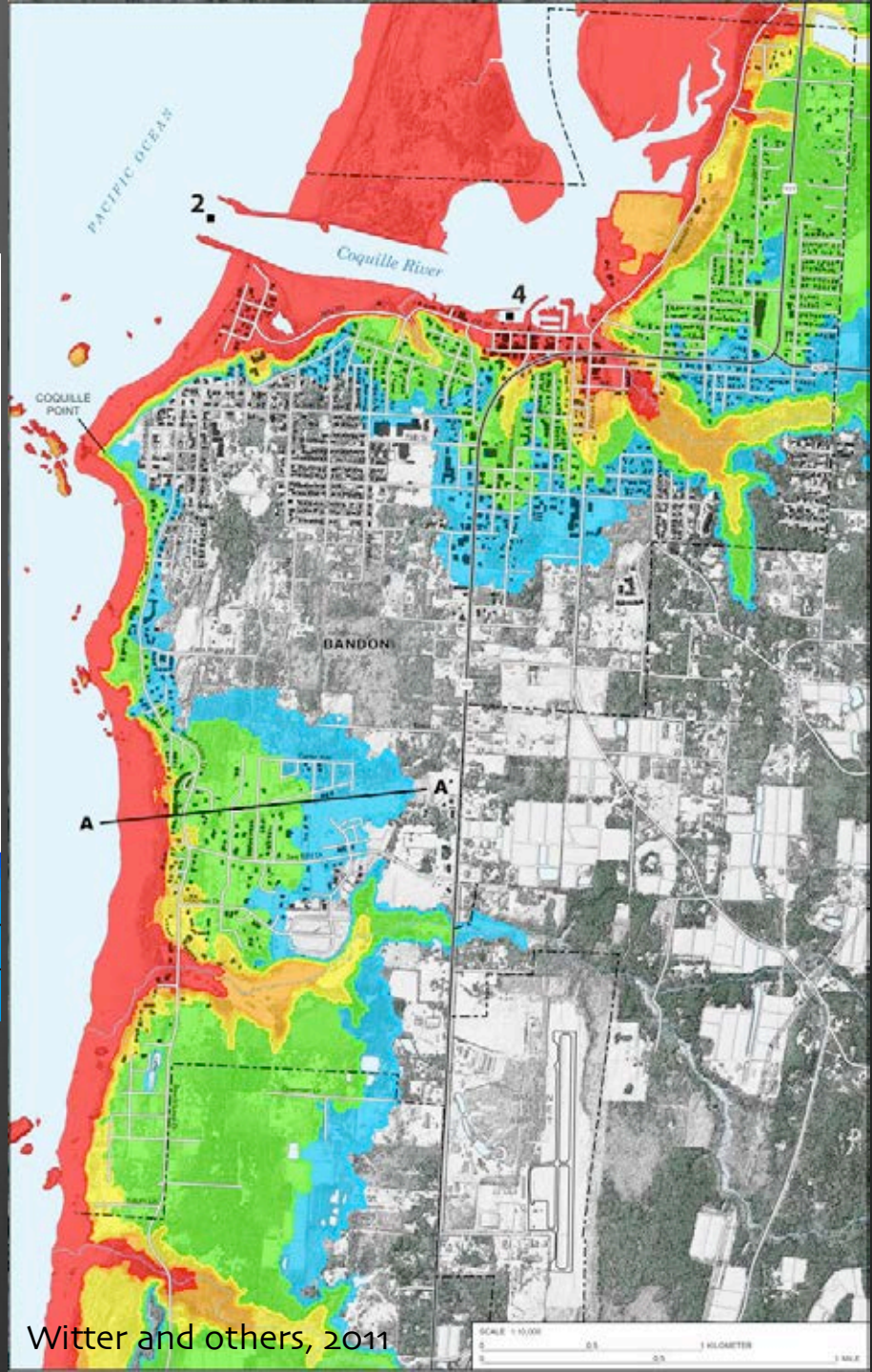
Kelsey and others, 2005; Nelson and others, 2006

Modeled inundation overtopped a lake outlet 6-m high



Modeling by Y. Zhang, OHSU;
Witter and others, 2012

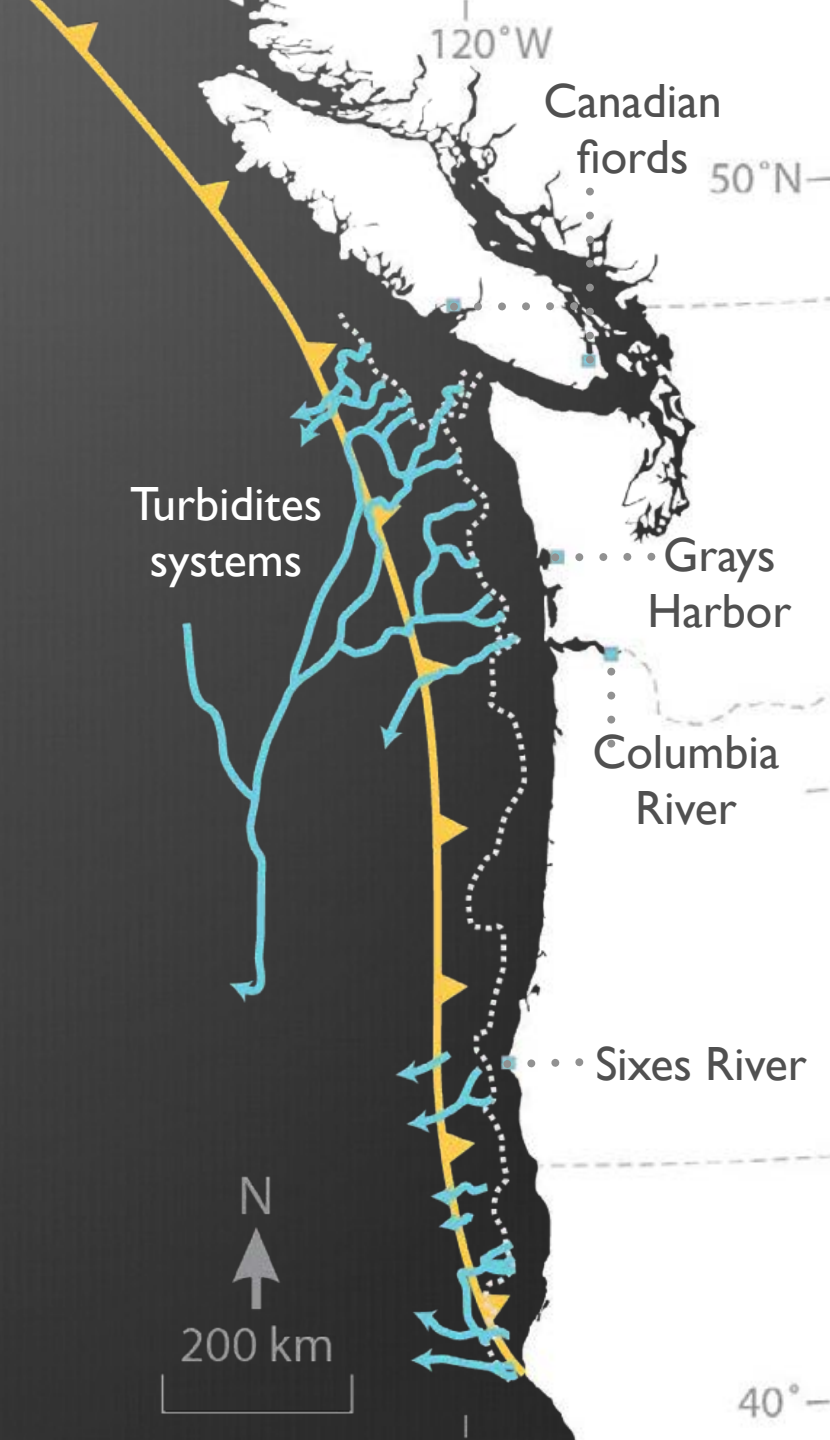
Refer to Witter and others (2011) for map explanation and cross section A-A′ at right.



Witter and others, 2011

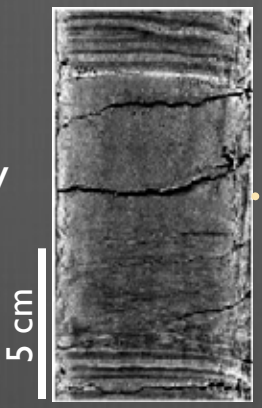
Seismic shaking

- Debris flow deposits in fiords and lakes
- Liquefaction on land
- Turbidites in offshore channels

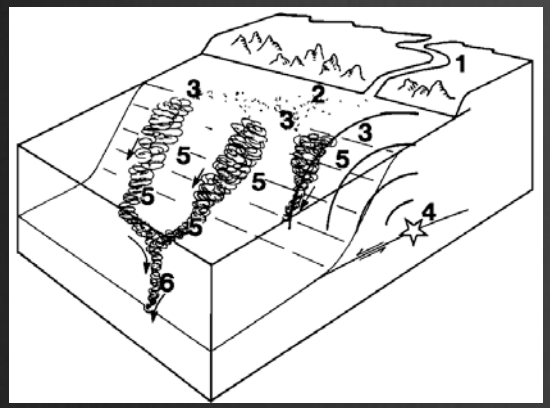


Saanich Inlet, B.C.

Earthquake-triggered debris flow deposits in a Canadian fiord



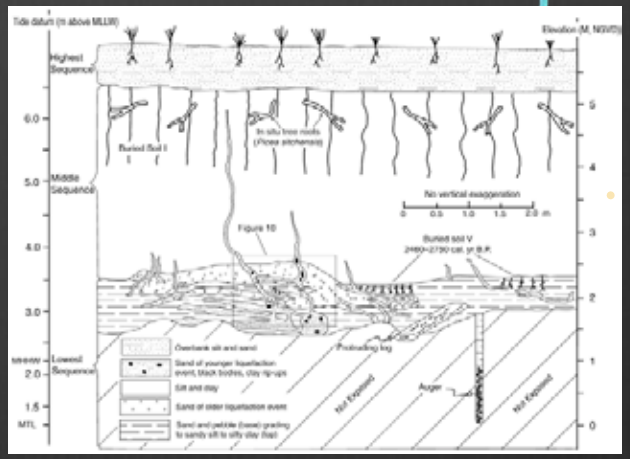
Blais-Stevens and Clague, 2001
Blais-Stevens et al., 2011



Adams, 1990

Cascadia turbidites

13 post-Mazama turbidites record great earthquakes on the Cascadia megathrust



Kelsey and others, 2002

Sixes River, Oregon

Intruded and vented sand record liquefaction caused by strong shaking

120°W

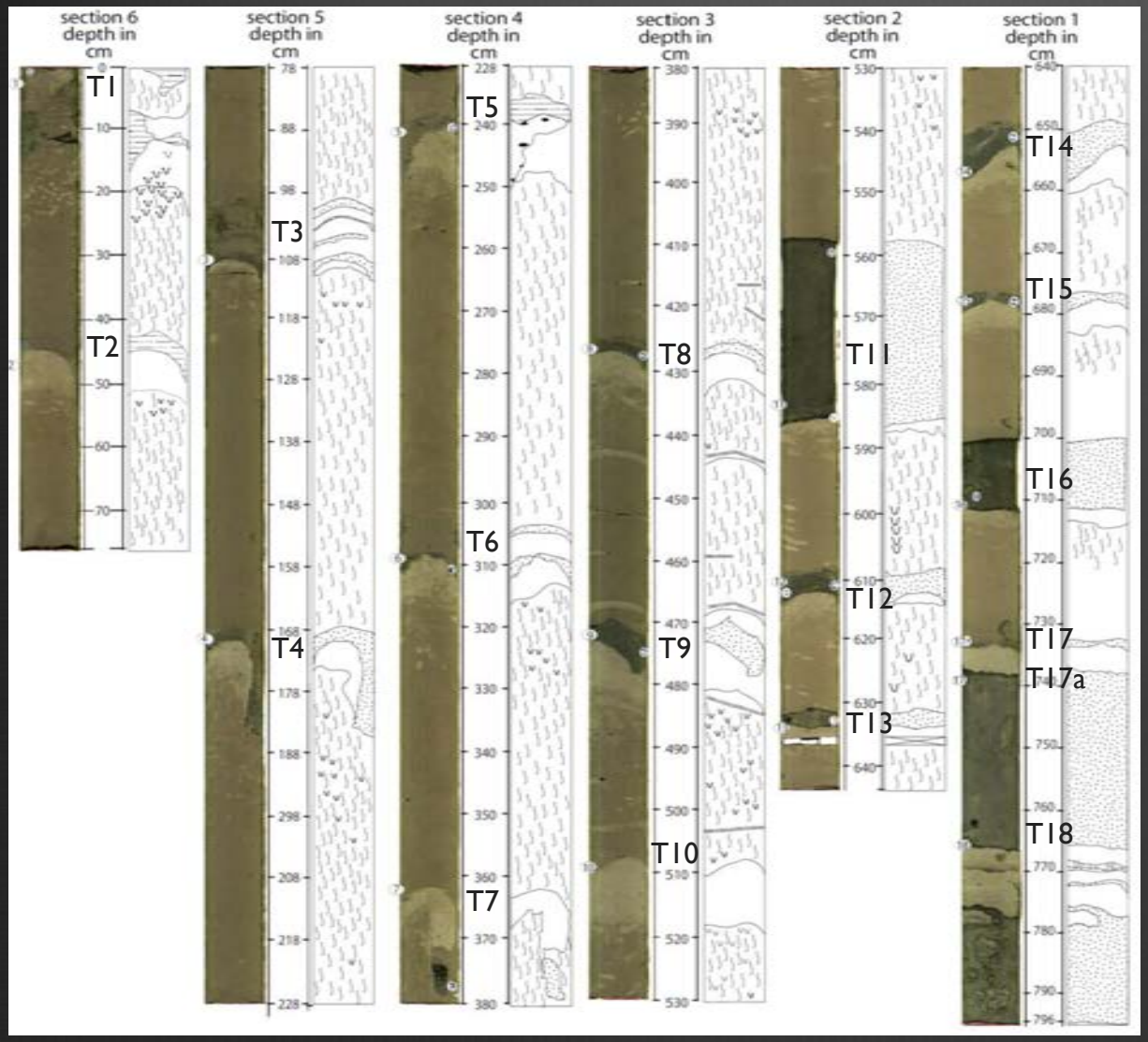
50°N

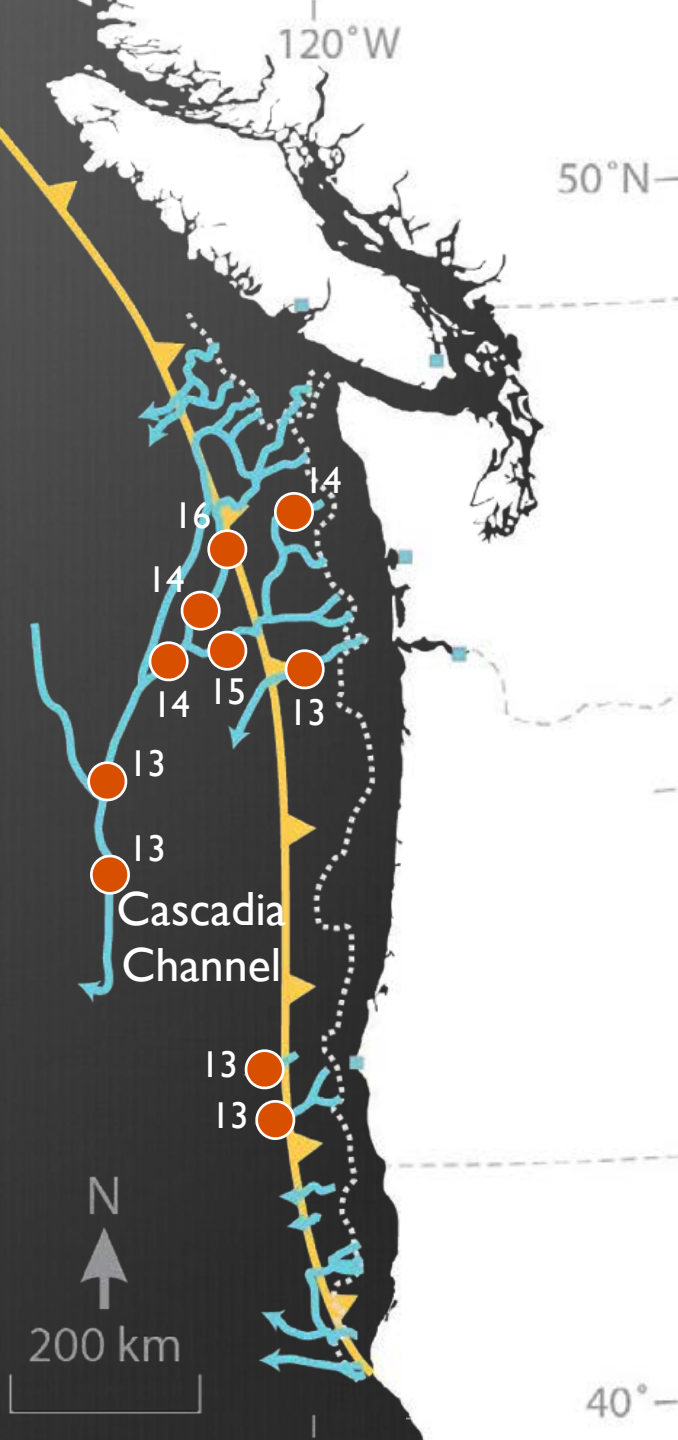
40°

200 km

Cascadia turbidites

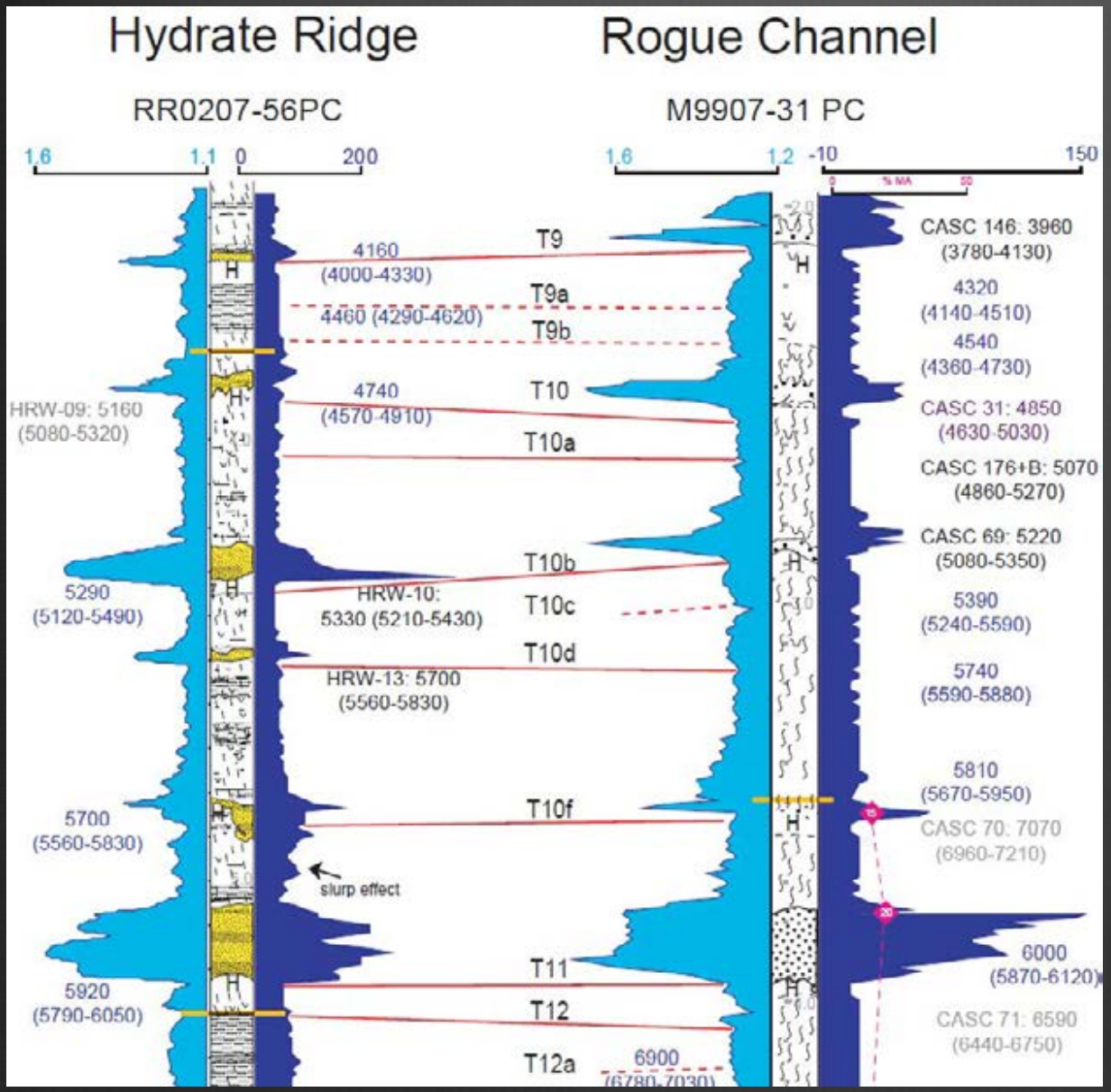
Cascadia Channel core M9907-25PC

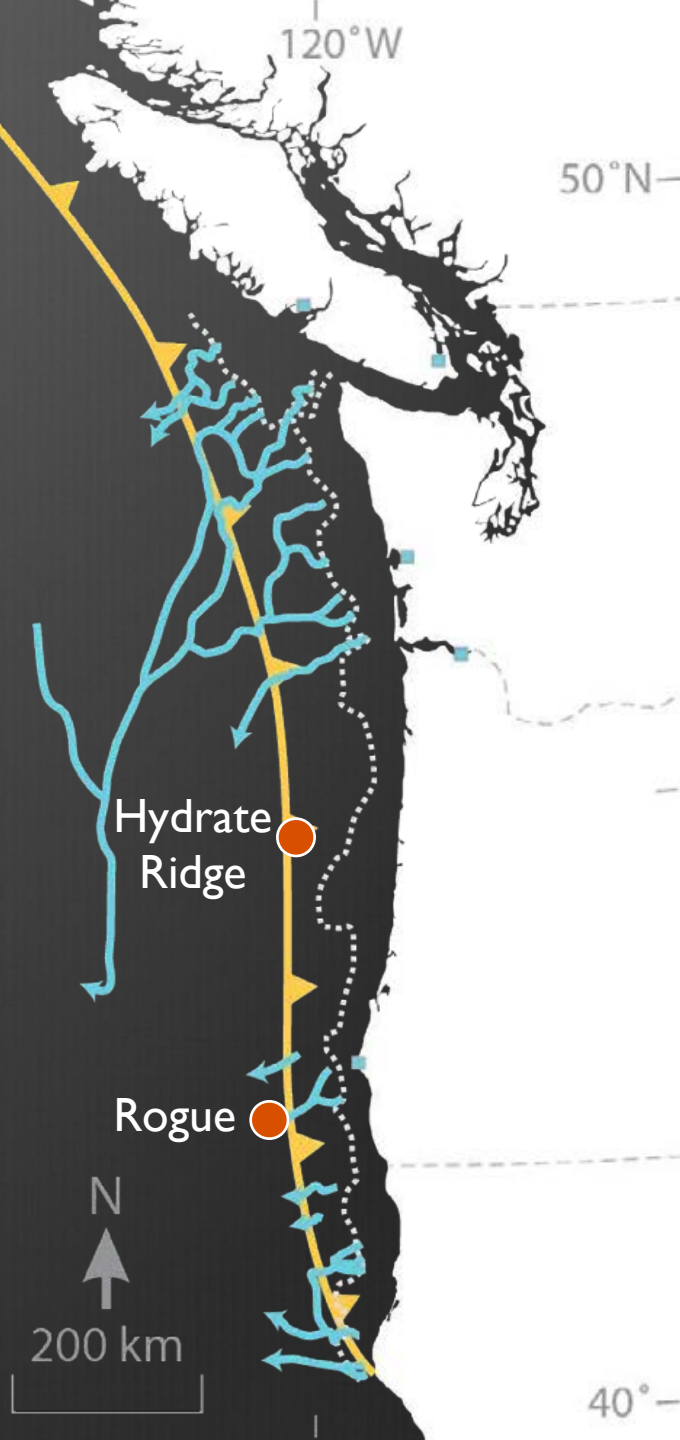




Goldfinger and others, 2012

Correlated by physical properties





Goldfinger and others, 2012

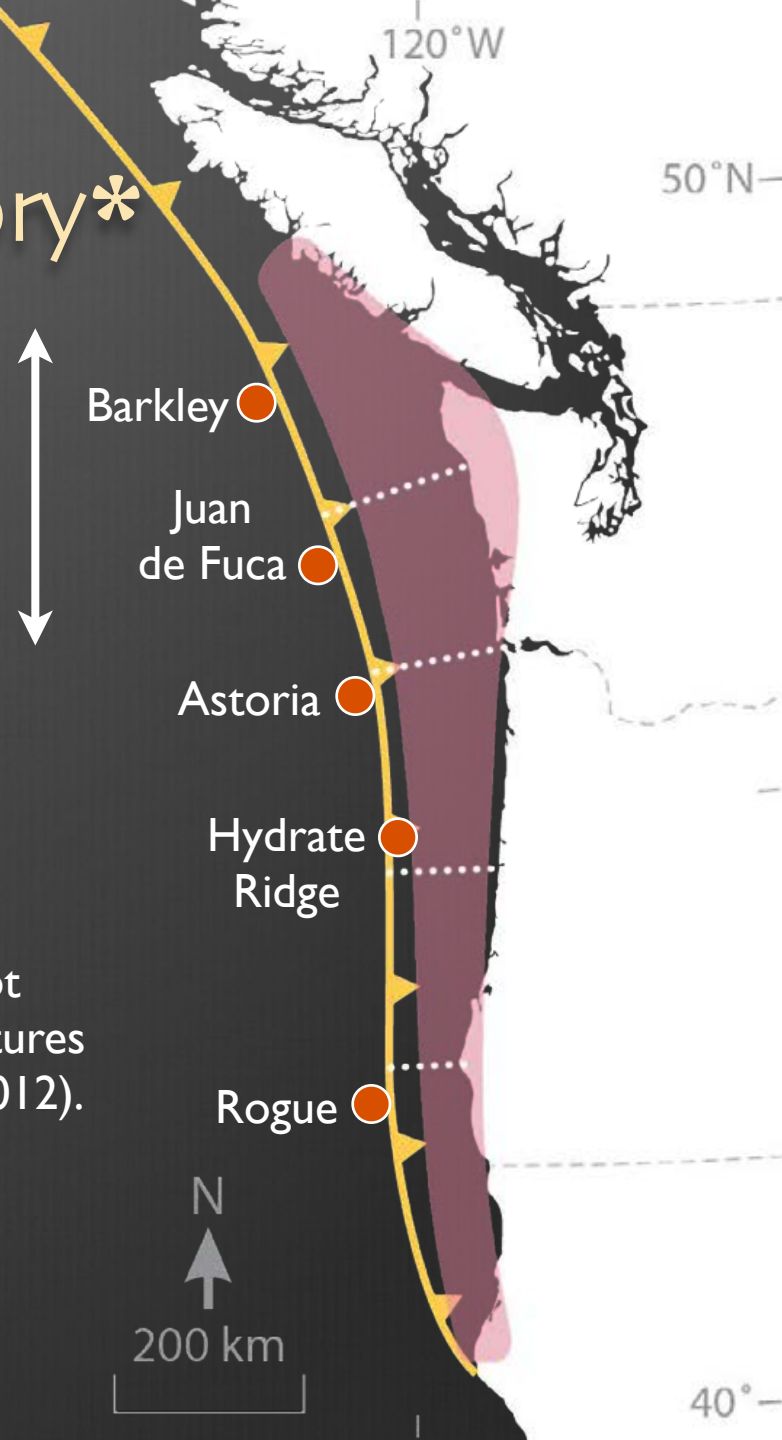
Turbidite record implies variable earthquake history*

Full-rip nine

19 turbidites

500-530 yr average recurrence interval

(Goldfinger and others, 2012)



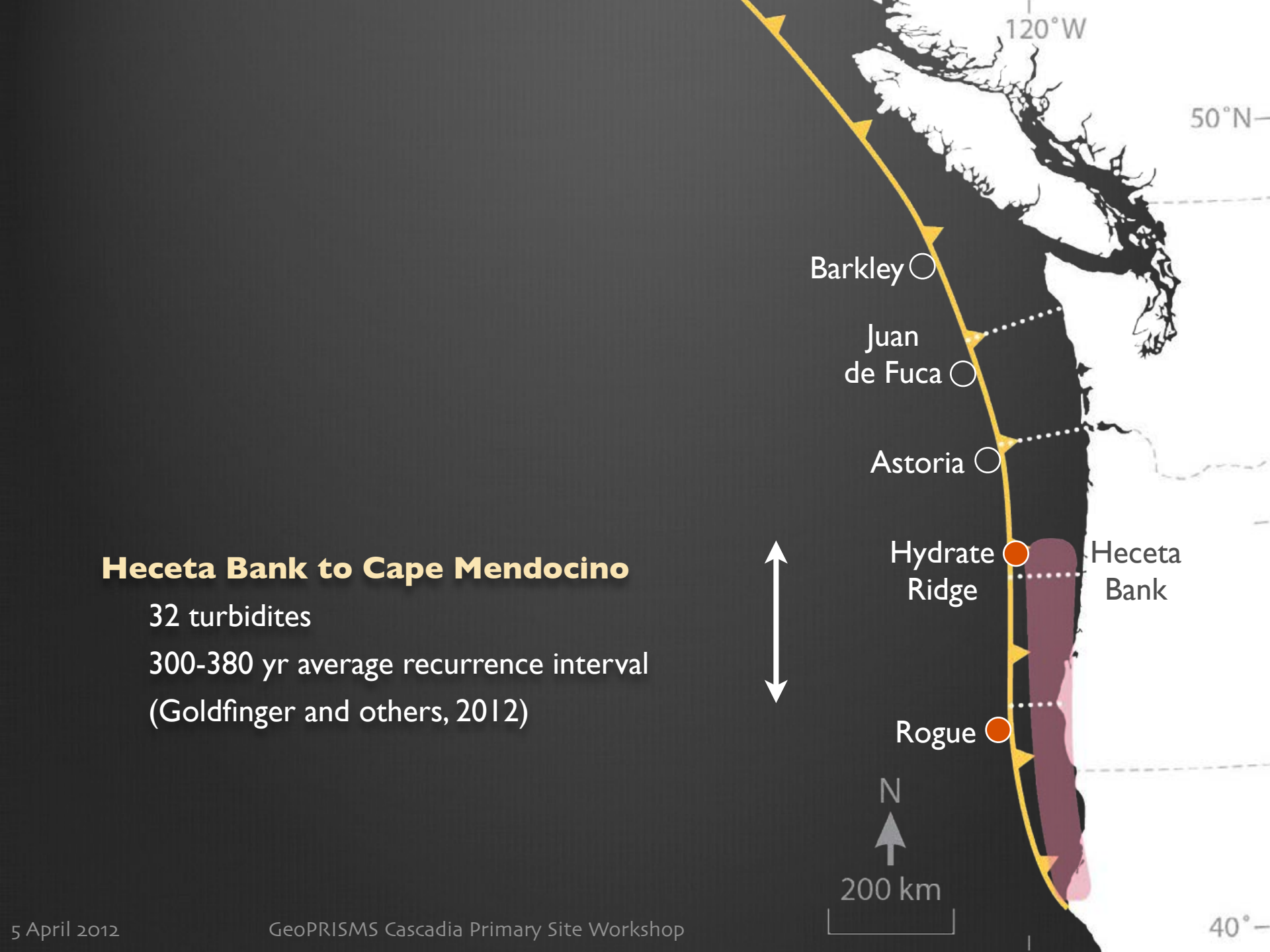
* Some consider it an open question whether or not turbidite evidence can distinguish between long ruptures and a series of shorter ones (Atwater and Griggs, 2012).

Nehalem Bank to Cape Mendocino

23 turbidites

410-500 yr average recurrence interval

(Goldfinger and others, 2012)



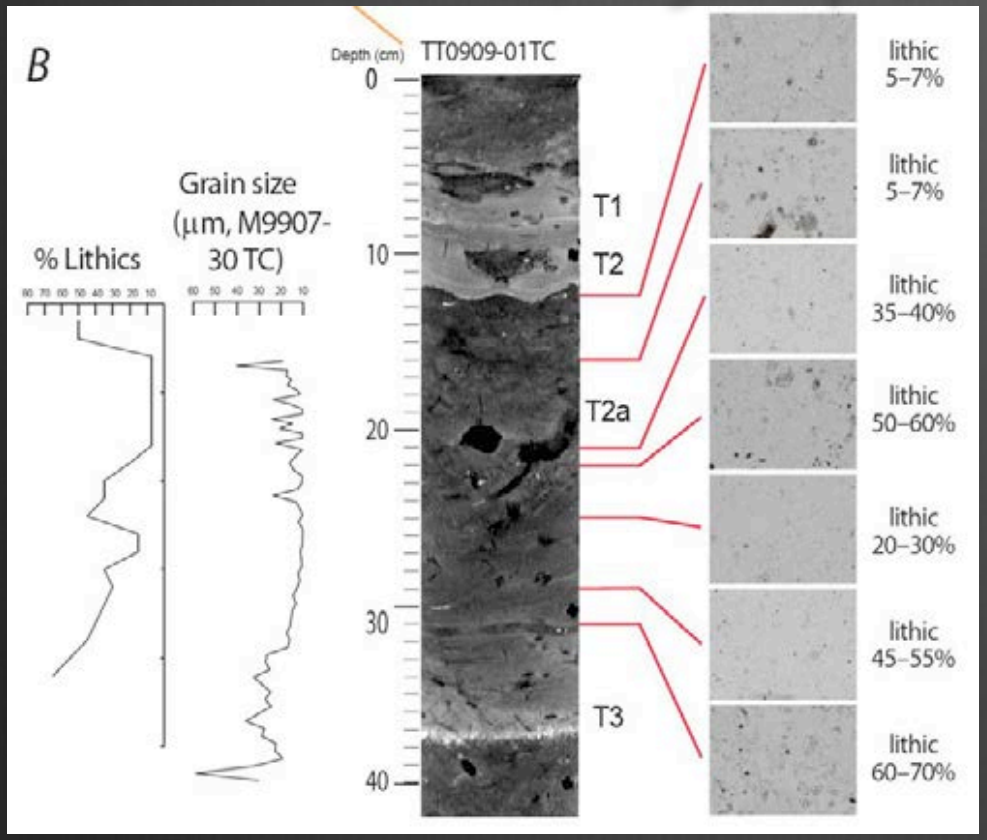
Heceta Bank to Cape Mendocino

32 turbidites

300-380 yr average recurrence interval

(Goldfinger and others, 2012)

Mud turbidite T2a, Rogue Apron



Goldfinger and others, 2012

Coquille Bank to Cape Mendocino

- 42 turbidites, 220-240 yr avg interval
- Assumes megathrust earthquakes triggered mud turbidites

Does northern Cascadia rupture only when the rest of the fault does?

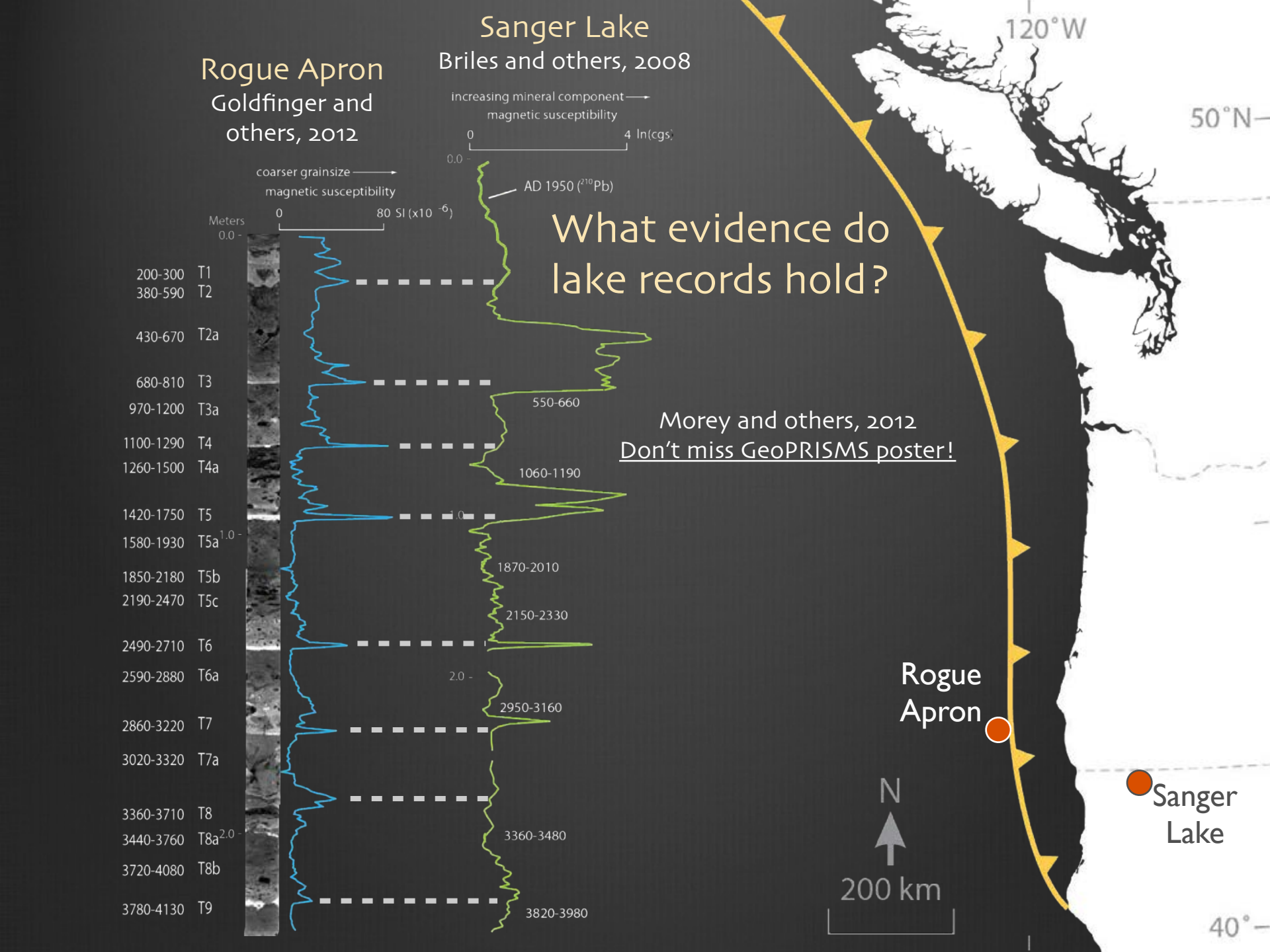
More frequent earthquakes in southern British Columbia? (Atwater and Griggs, 2012)

300-yr average interval between tsunamis at Discovery Bay (Williams and others, 2005)

Uncertainties

Frankel, 2011, USGS Open-File Report 2011-1310
Atwater and Griggs, 2012, USGS Open-File Report 2012-1043

1. Where does confluence test demonstrate coeval rupture?
2. How much does turbidite frequency vary with distance from steep slopes and volume of sediment sources?
3. Which mud turbidites can be explained by storms or floods, landslide-dam outbursts, or earthquakes other than great thrust events?
4. How unique are turbidite correlations inferred from geophysical logs and limiting radiocarbon ages?
5. In the coarse-fraction pulses interpreted as paleo-seismograms, what are the signals from flow dynamics?


Rogue Apron
Goldfinger and others, 2012
Sanger Lake
Briles and others, 2008
increasing mineral component
magnetic susceptibility
0
4 ln(cgs)
coarser grainsize
magnetic susceptibility
0
80 SI (x10 -6)
Meters
0.0
AD 1950 (210Pb)
200-300 T1
380-590 T2
430-670 T2a
680-810 T3
970-1200 T3a
1100-1290 T4
1260-1500 T4a
1420-1750 T5
1580-1930 T5a
1850-2180 T5b
2190-2470 T5c
2490-2710 T6
2590-2880 T6a
2860-3220 T7
3020-3320 T7a
3360-3710 T8
3440-3760 T8a
3720-4080 T8b
3780-4130 T9
1.0
2.0
550-660
1060-1190
1870-2010
2150-2330
2950-3160
3360-3480
3820-3980
What evidence do lake records hold?
Morey and others, 2012
Don't miss GeoPRISMS poster!
120°W
50°N
40°
Rogue Apron
Sanger Lake
N
200 km

Breakthroughs since the mid 1990s

Cascadia's seismic potential of M9

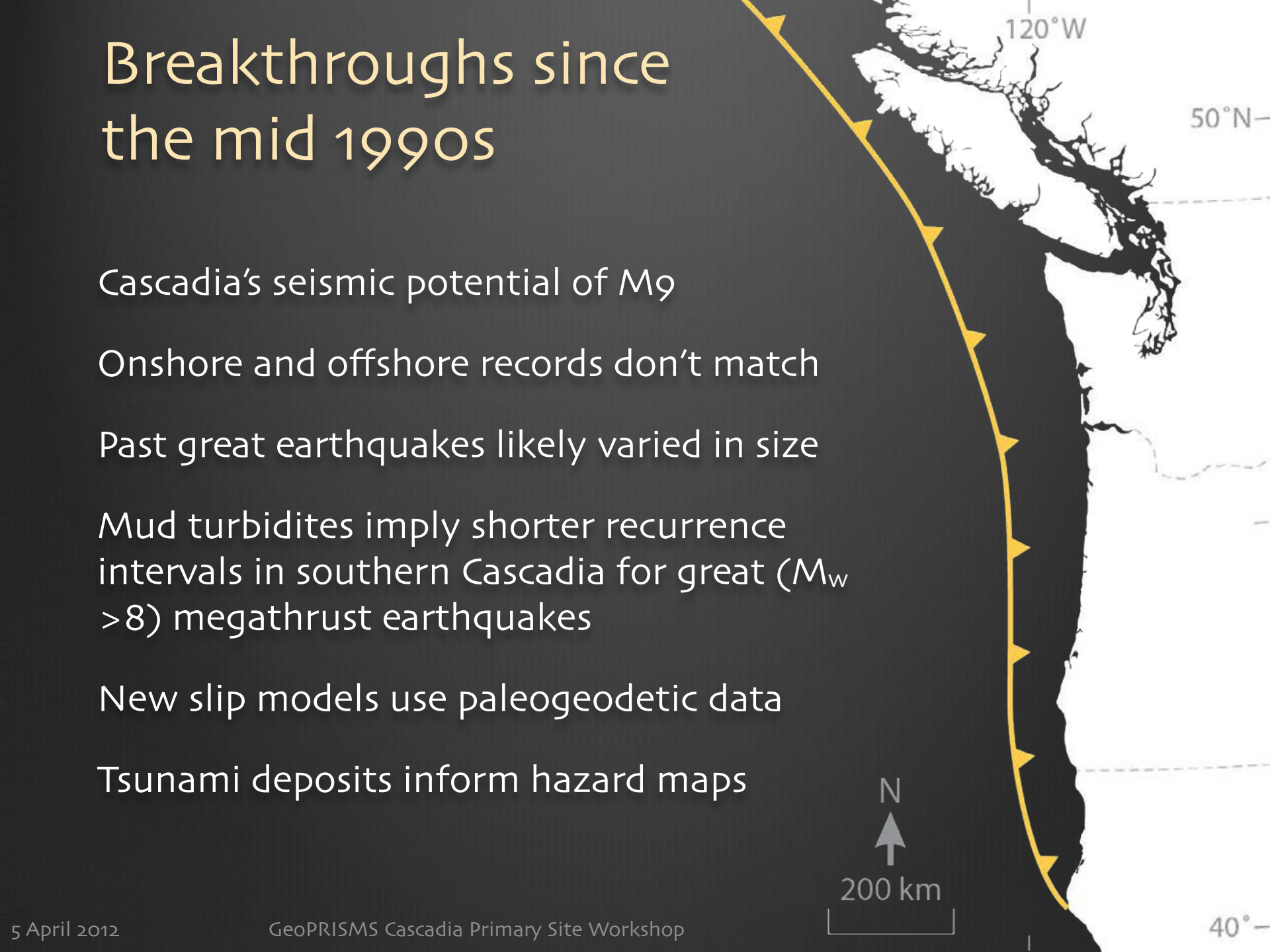
Onshore and offshore records don't match

Past great earthquakes likely varied in size

Mud turbidites imply shorter recurrence intervals in southern Cascadia for great (M_w >8) megathrust earthquakes

New slip models use paleogeodetic data

Tsunami deposits inform hazard maps



Outstanding questions

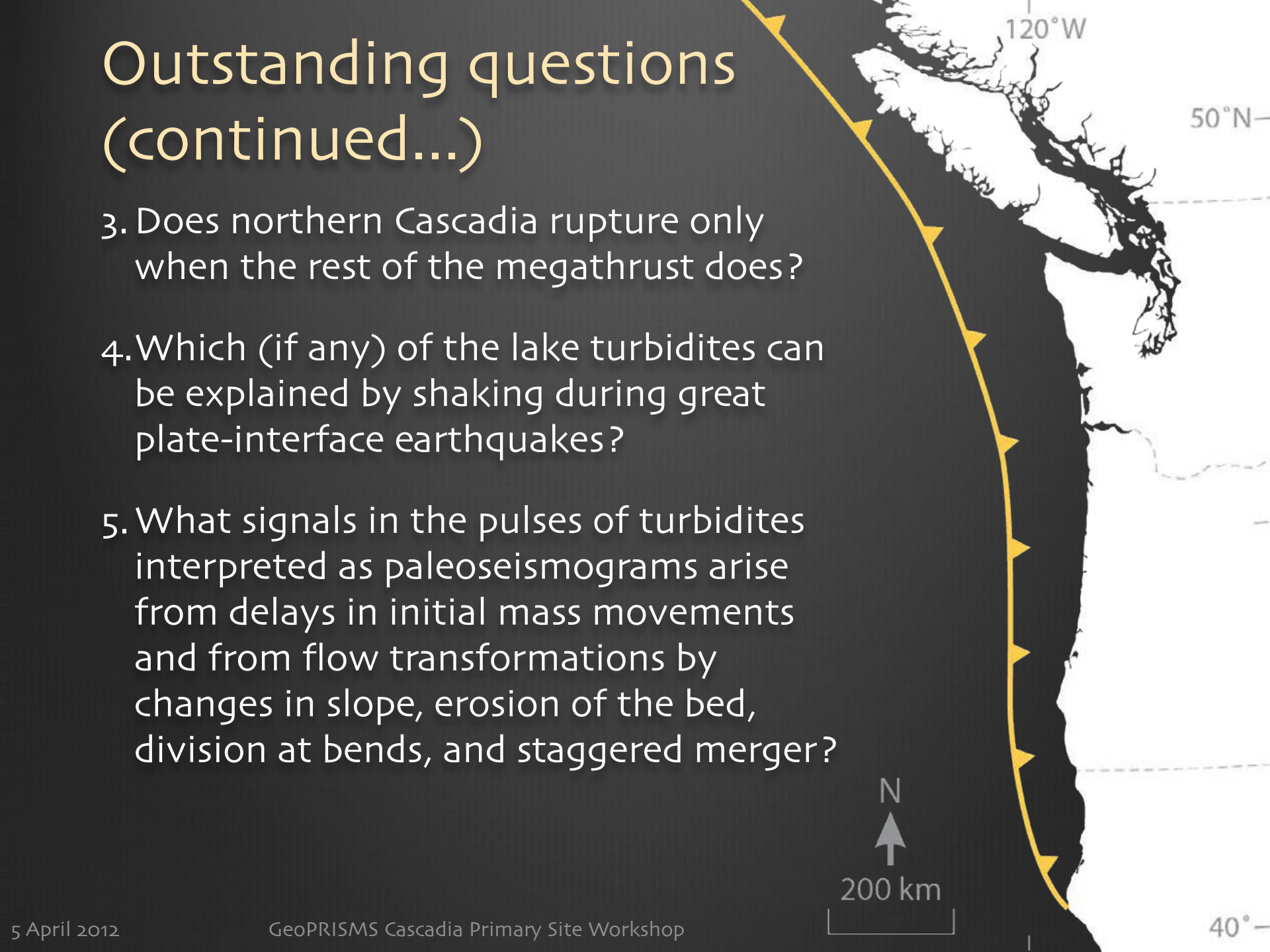
1. How did coseismic slip vary for predecessors of the 1700 earthquake?
   - Do successive earthquakes vary in size?
   - How does slip vary spatially along the megathrust?
2. Do all mud turbidites in southern Cascadia record plate interface earthquakes, or can some be explained by storms or floods, landslide-dam outbursts, or earthquakes other than megathrust events?

Outstanding questions (continued…)

3. Does northern Cascadia rupture only when the rest of the megathrust does?

4. Which (if any) of the lake turbidites can be explained by shaking during great plate-interface earthquakes?

5. What signals in the pulses of turbidites interpreted as paleoseismograms arise from delays in initial mass movements and from flow transformations by changes in slope, erosion of the bed, division at bends, and staggered merger?



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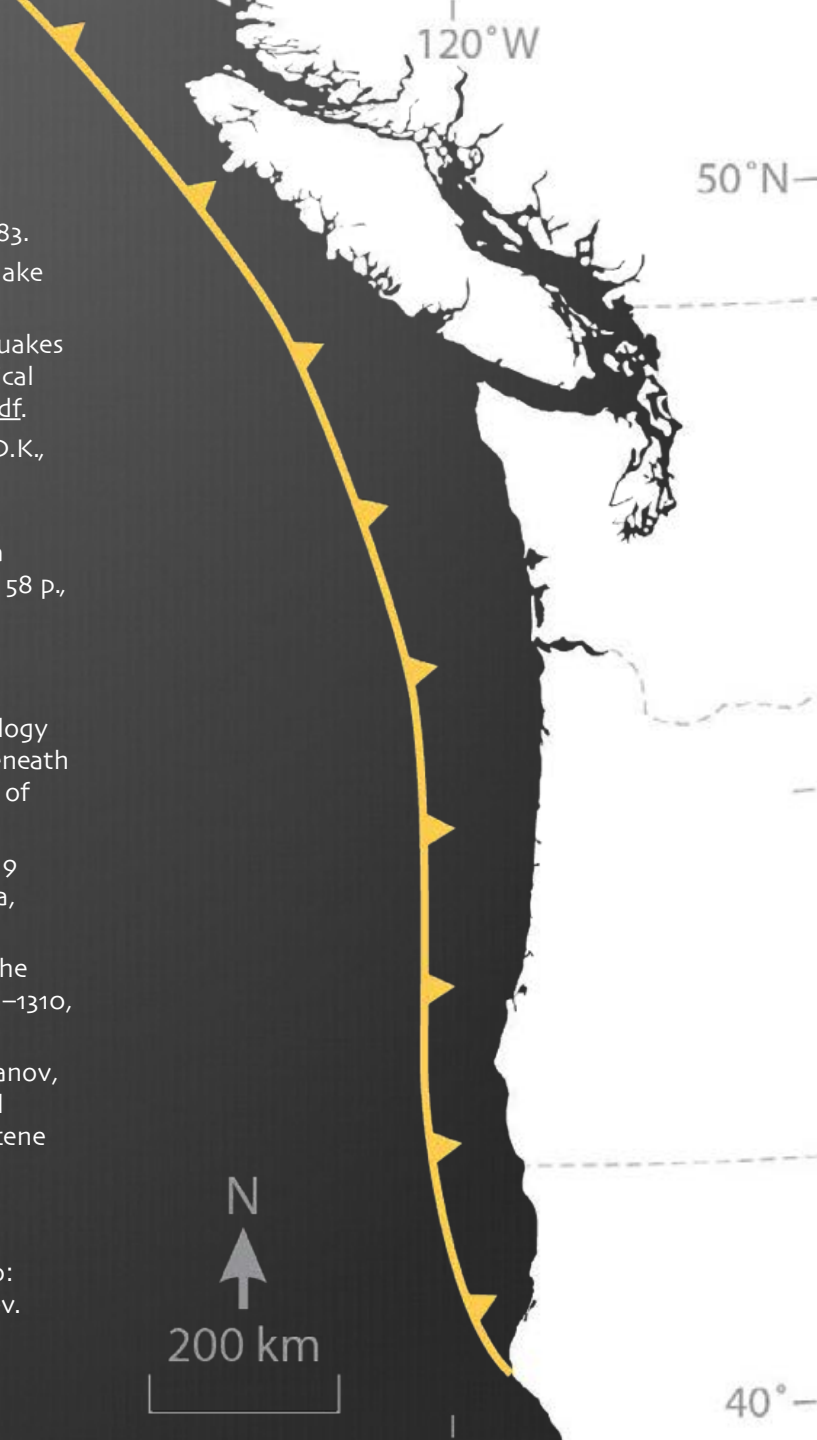

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