RECENT COMPREHENSIVE TSUNAMI MODELING FOR COASTAL OREGON

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Pardee Keynote Symposium *Great Earthquakes, the Cascadia Subduction Zone, and Society* II (GSA Session No. 237)

Tuesday, 21 October 2014

The 2007-2013 Scientific Team

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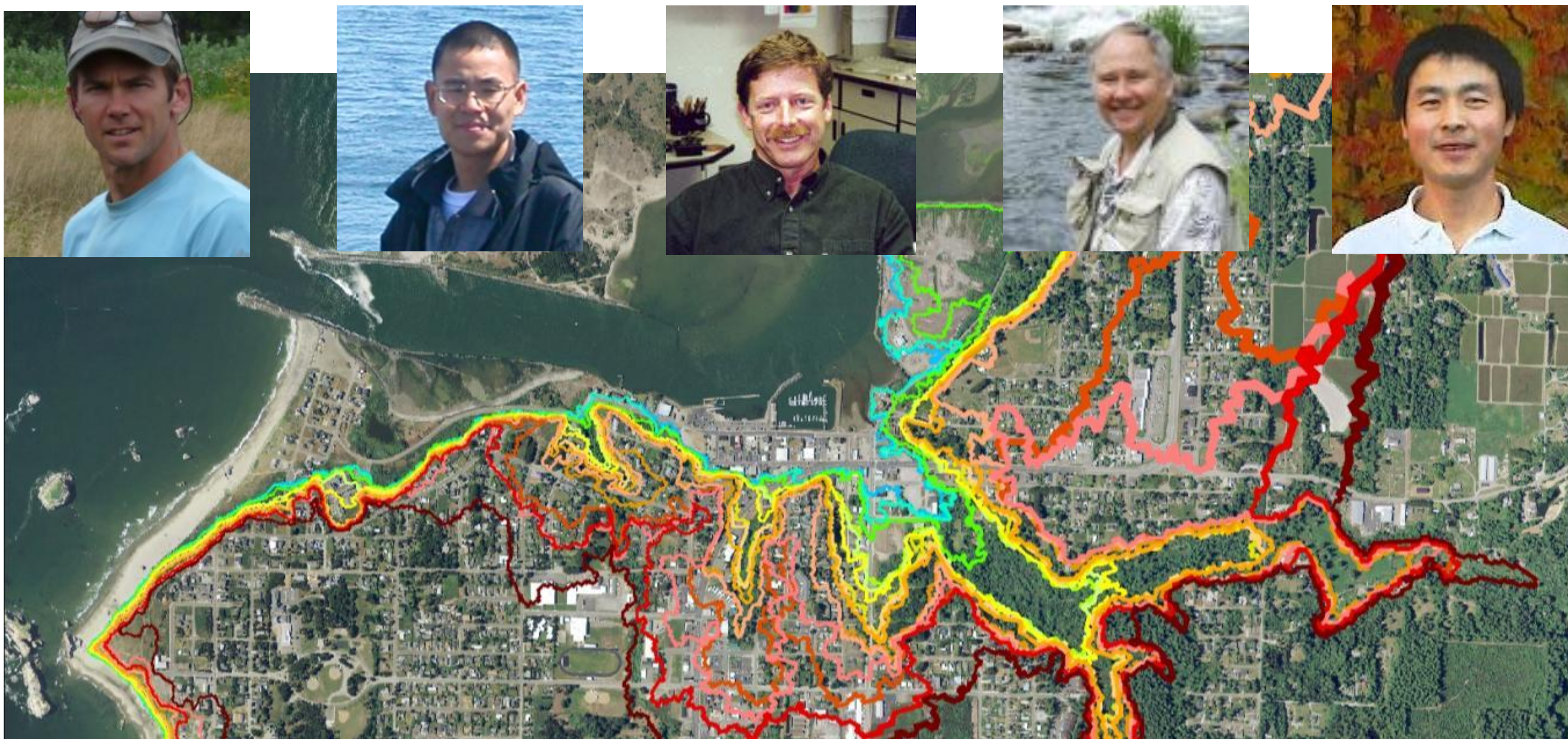


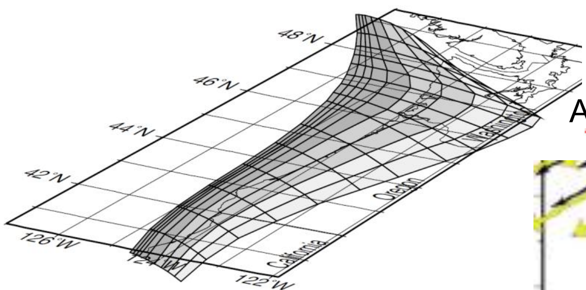
Overview of Tsunami Modeling

- **GUIDING PHILOSOPHY:**
  Most serious threat = local Cascadia subduction zone (CSZ) tsunamis
- **THUS with limited resources we:**
  1. Limited distant tsunami scenarios to maximum considered historical and hypothetical events.
  2. Limited local CSZ scenarios to best deterministic representation of the 10,000-yr paleoseismic record.
  3. Used a static tide at MHHW (mean higher high water).
  4. Used the finite element model **SELFE** with unstructured grids:
     - Highly efficient, parallel processing
     - Simulates very small features such as jetties without multiple, nested grids
  5. Tested CSZ sources for compatibility to data from:
     - Paleotsunami deposits
     - Paleosubsidence

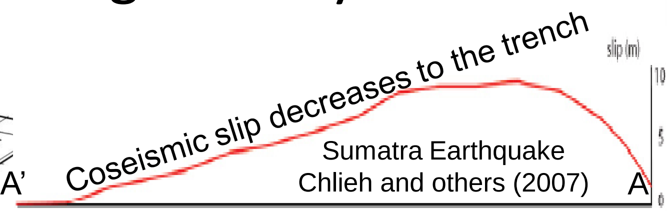
CSZ Fault Models

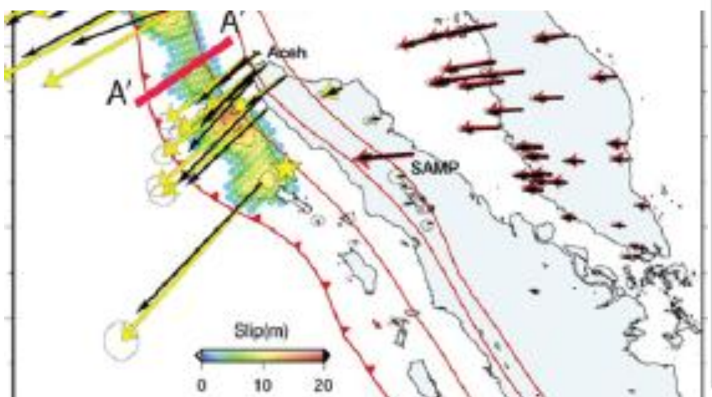
1. Megathrust rupture (whole SZ)
2. Splay fault rupture (at Pleis.-Plioc. contact)
3. Deep megathrust rupture
   (ends at Pleistocene wedge)

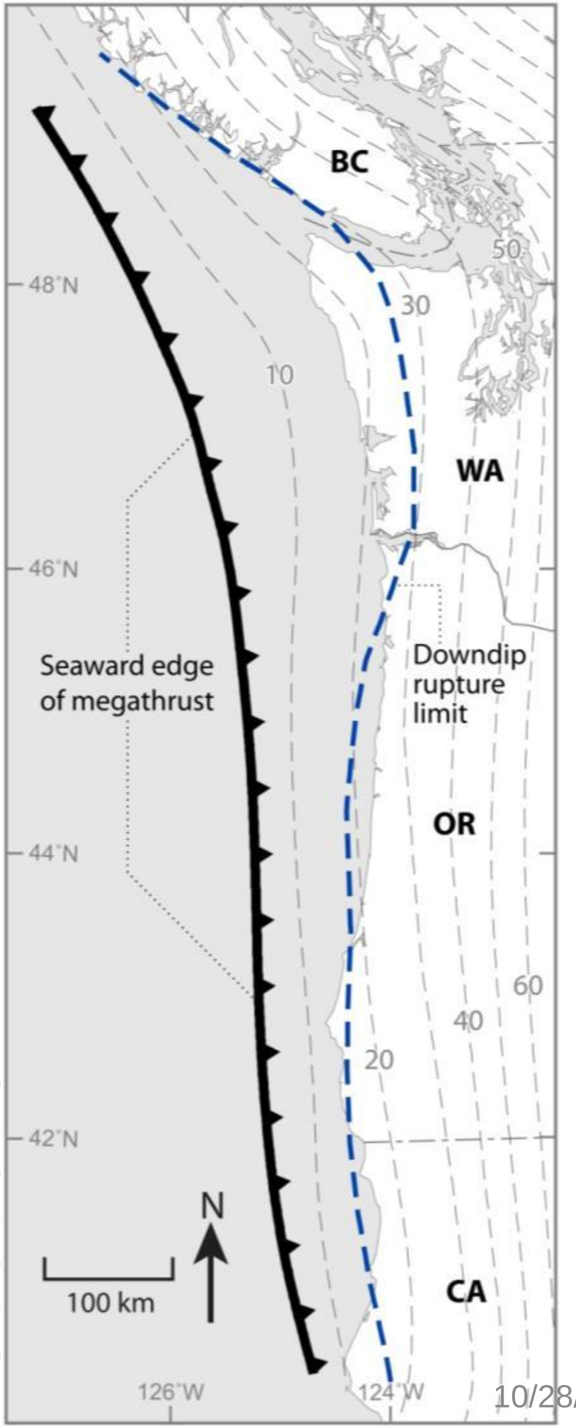
- Fault geometry of McCrory et al. (2004)
- Okada (1985) point source model
- Dynamic coulomb wedge theory
  (Wang and Hu, 2006)



McCrory et al. (2004)

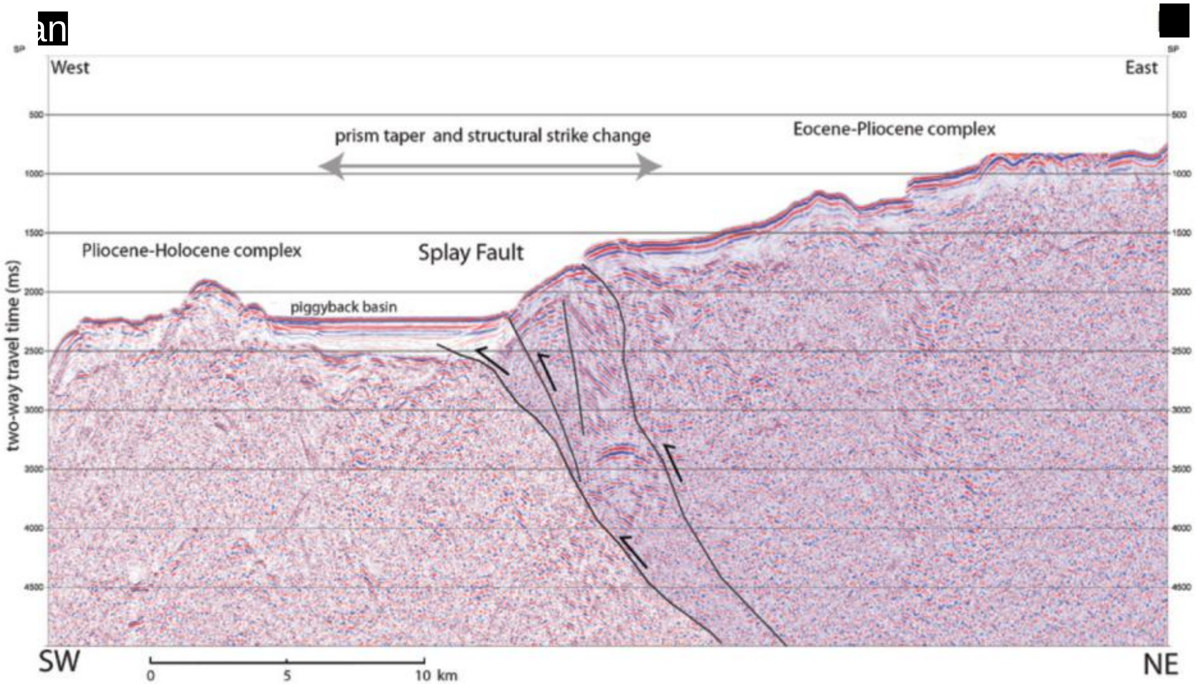


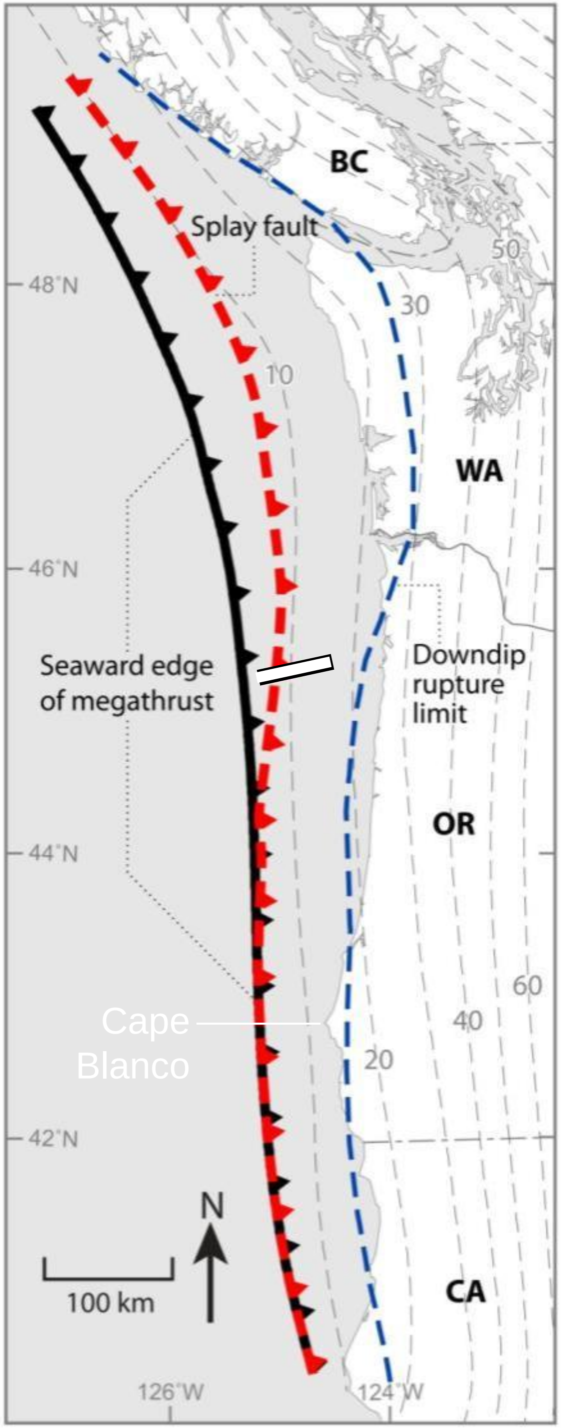




Fault Model

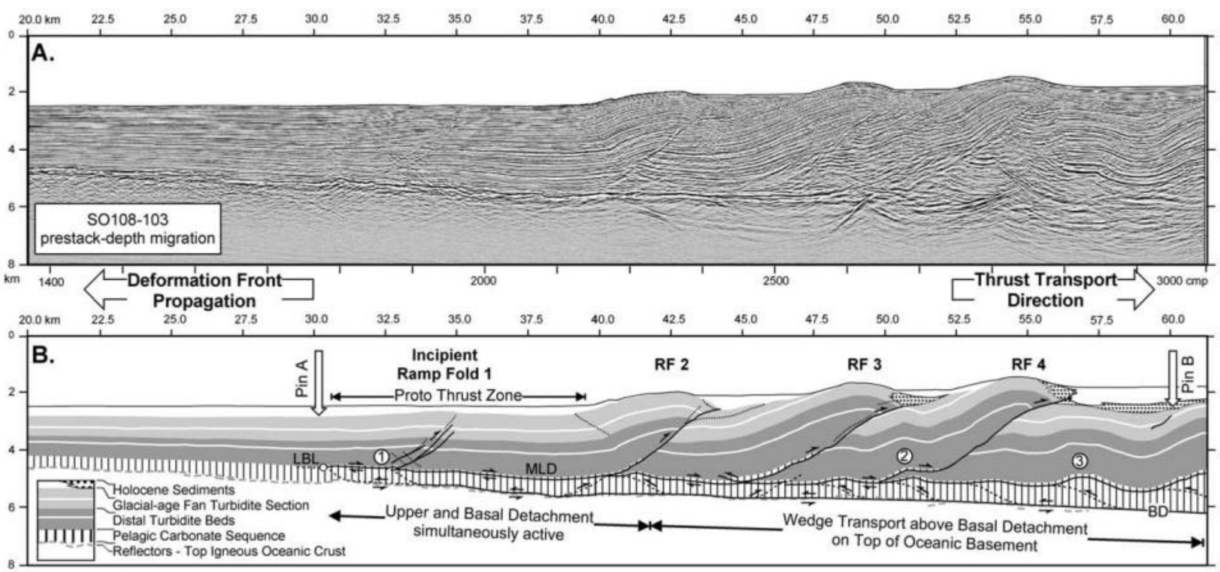
- Splay fault rupture
  - Imaged in seismic lines offshore
  - 30˚ dip; merges with megathrust
  - Slip is partitioned to splay fault



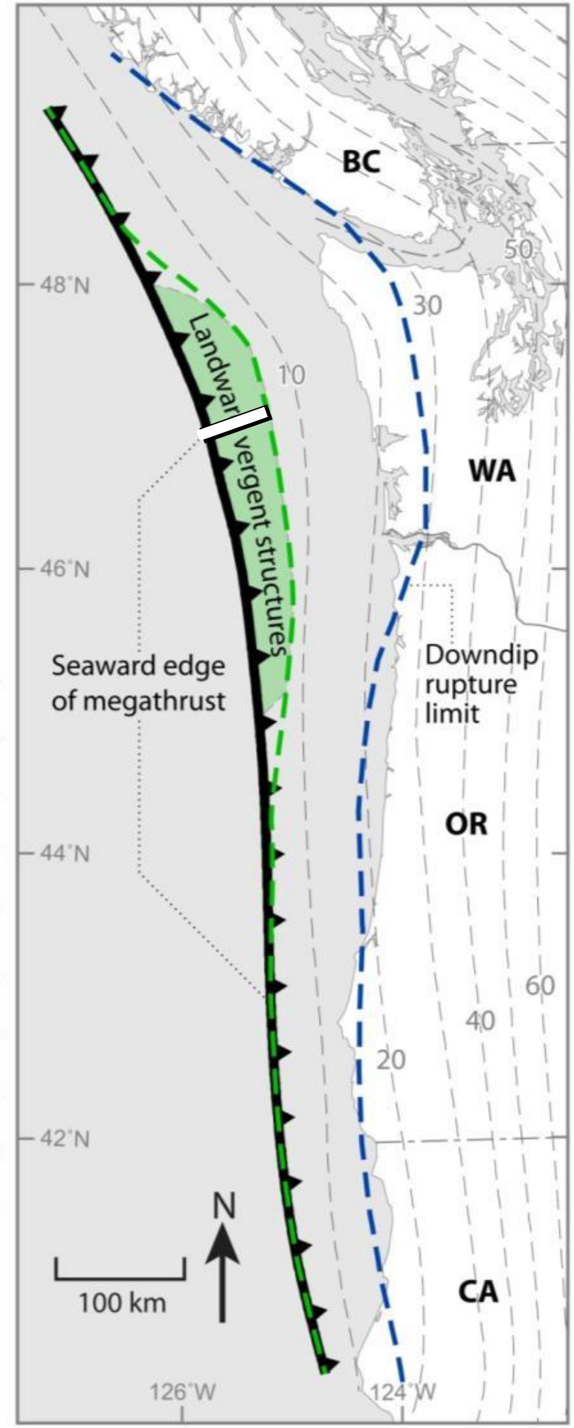


Fault Model

- Deep megathrust rupture
  - “Deep buried rupture”
  - Coseismic slip limited to inner, Tertiary wedge
  - Outer wedge poorly coupled

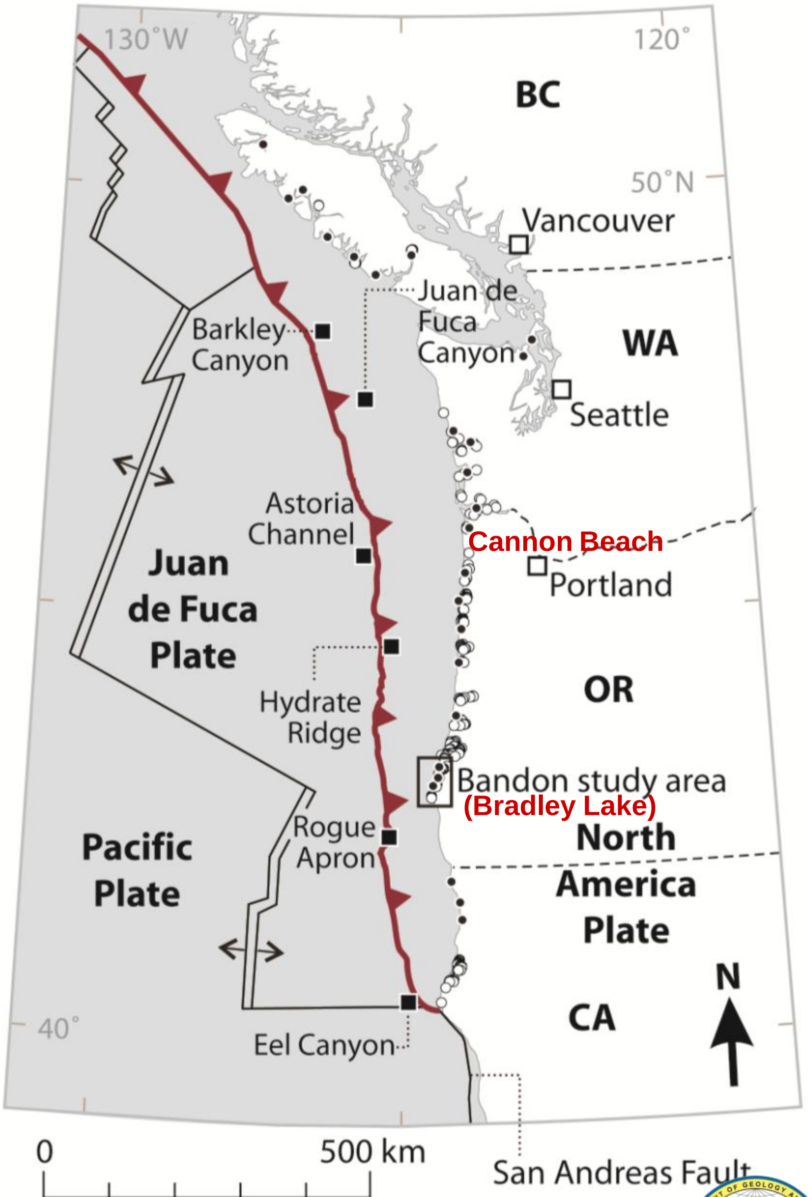


Adam et al., 2004



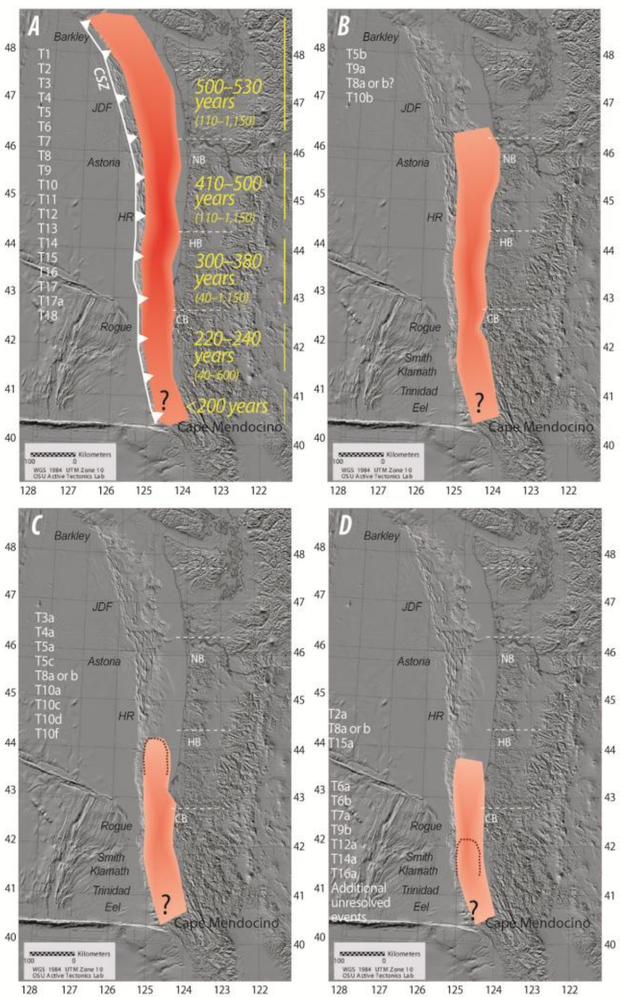
Use paleoseismology as the foundation for tsunami modeling

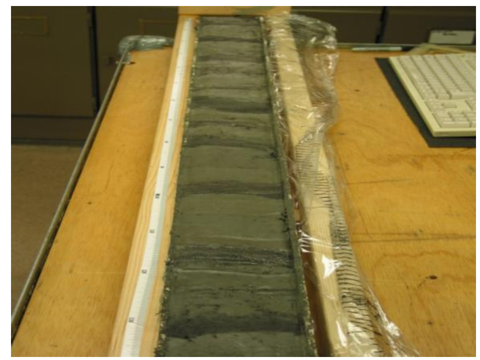
- 10,000-yr record of deep sea turbidites
- Coastal evidence of coseismic subsidence and tsunami inundation
- Tsunami deposits in an Oregon coastal lake (**Bradley Lake**)
- Tsunami deposits in an Oregon bog (Ecola Creek marsh, **Cannon Beach**)

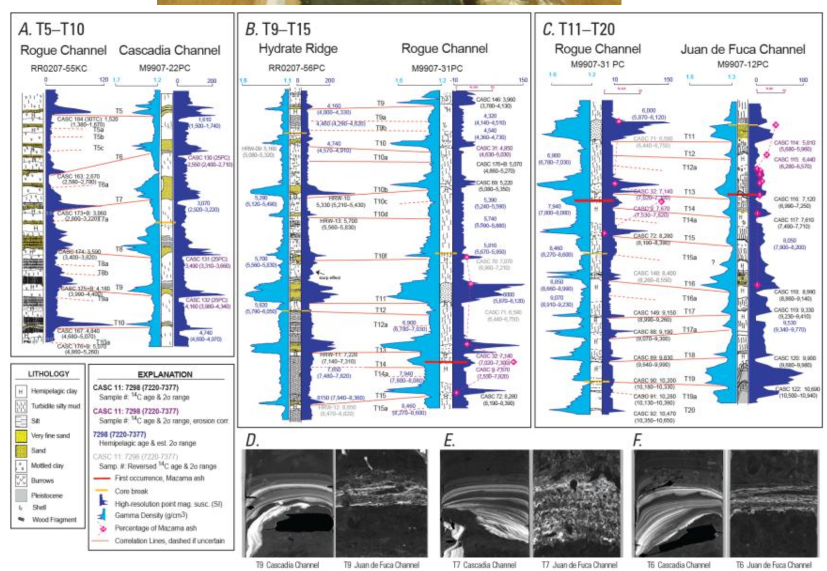


Assumptions for CSZ logic tree:

- Full-margin ruptures efficiently depict the tsunami hazard (e.g., Priest et al., 2014)
- Peak slip deficits ≈ times between full-margin (sand) turbidites x convergence rate.
- Partial ruptures (mud turbidites) decrease slip deficit available to full-margin sources.

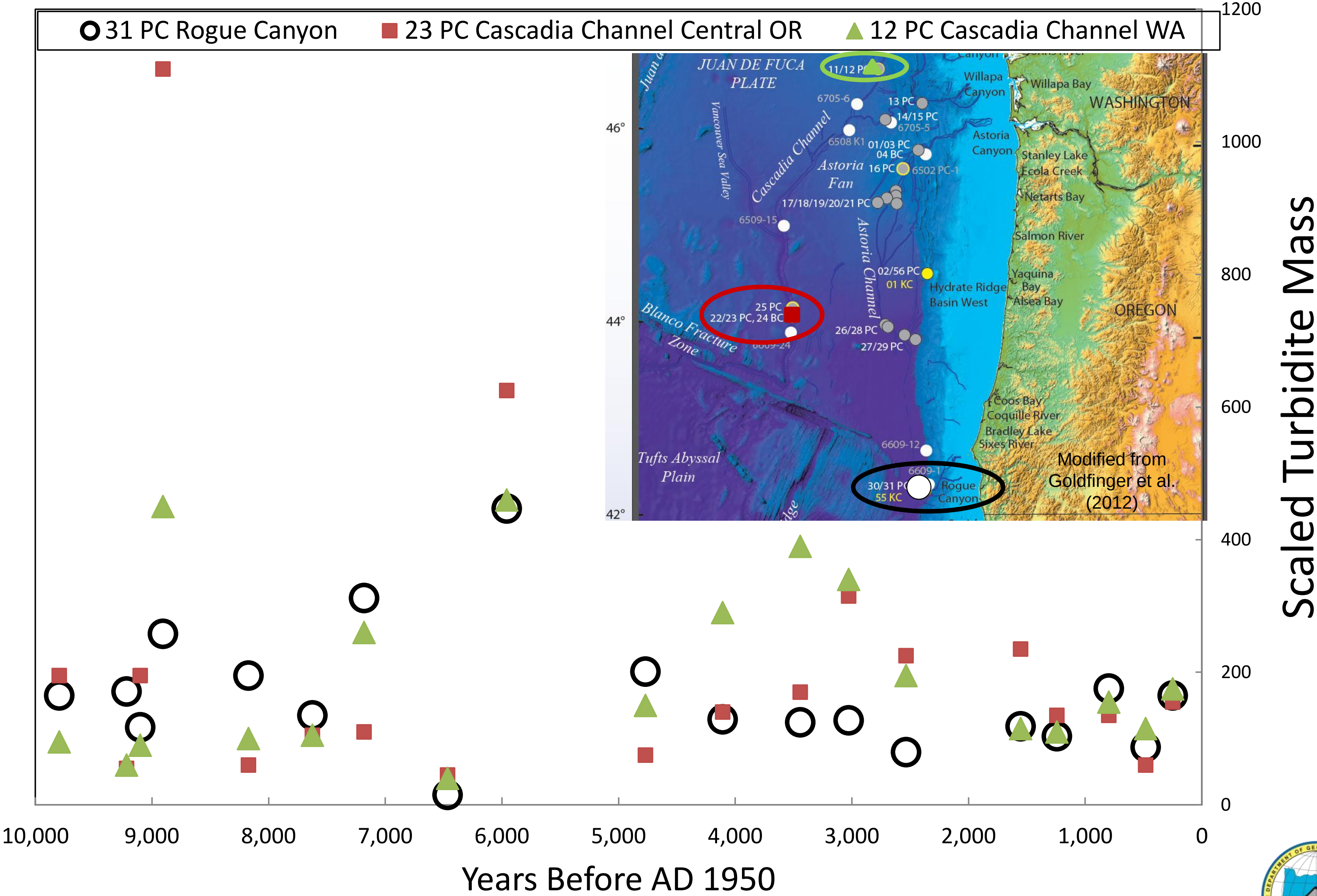




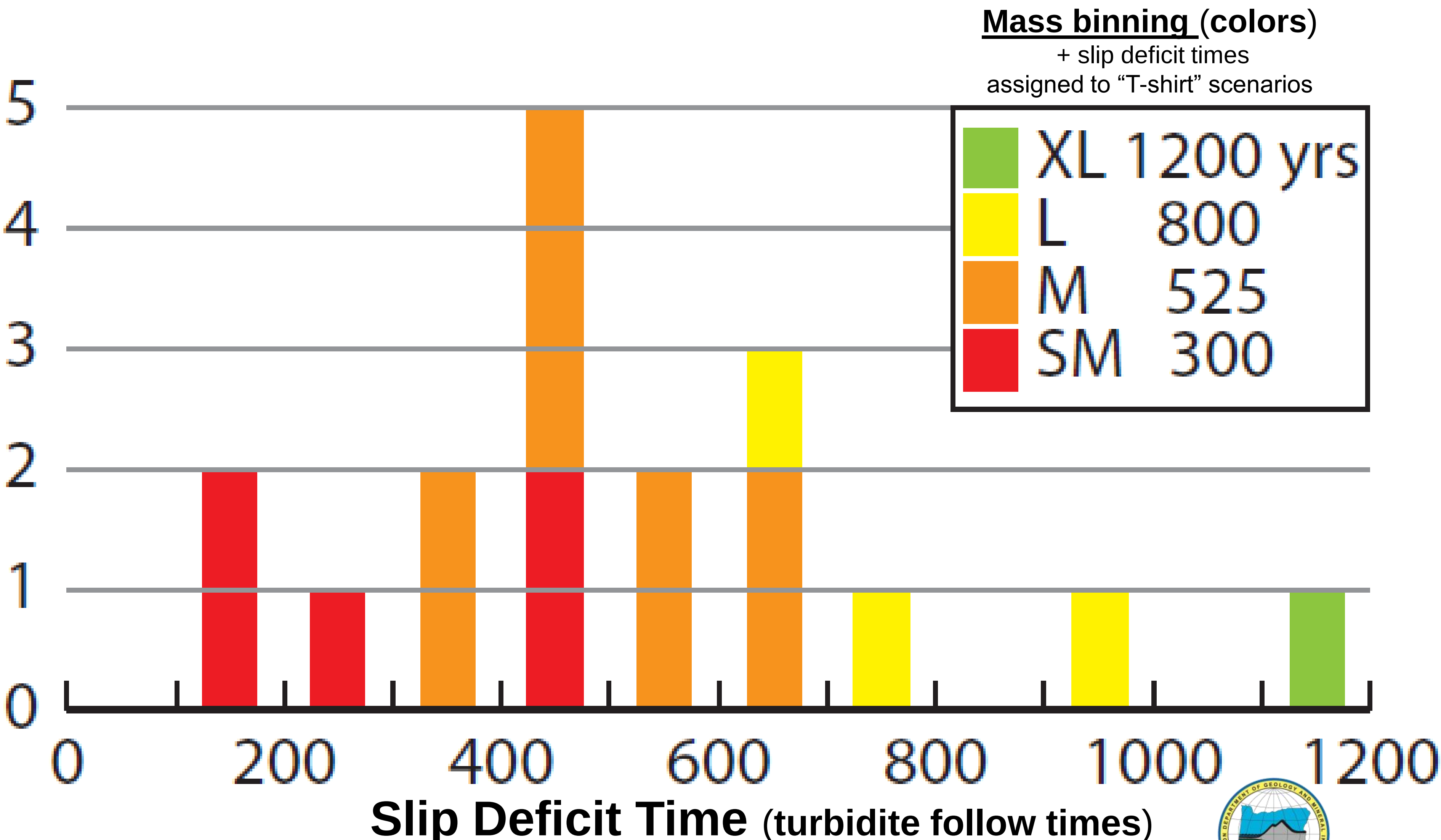


Picture at top is from Chris Goldfinger; illustrations are from or modified from Goldfinger et al. (2012).

Full-Margin Turbidite Mass vs Age



Comparison of binning: Numbers (of 19) full-margin Cascadia turbidites binned by **slip deficit (follow) times** versus **mass** (Witter et al., 2011; 2013)



<u>Minimum peak CSZ slip</u> needed to account for coastal paleotsunami deposits at Bradley Lake and Cannon Beach: **8-15 m**

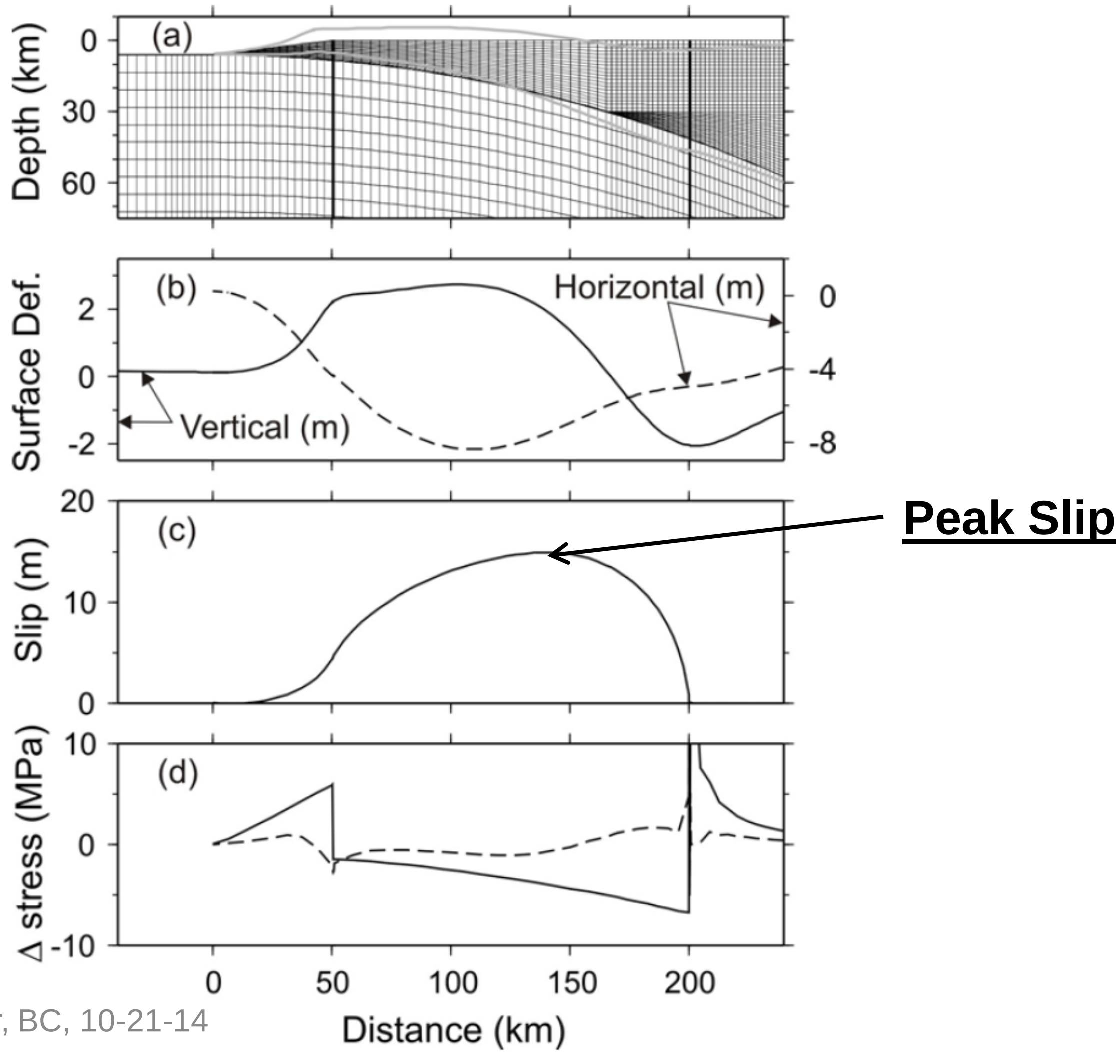
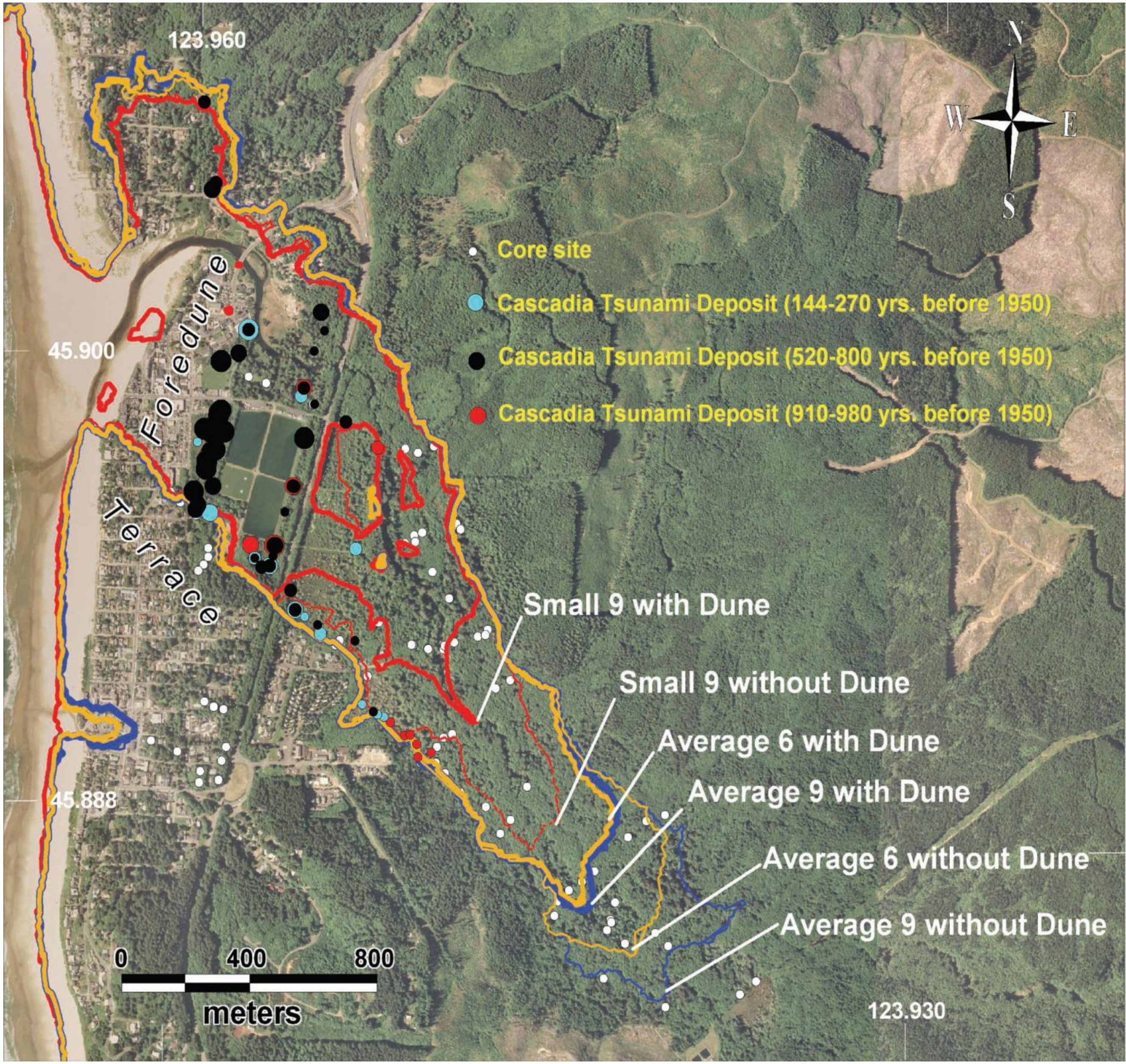


Illustration from
Wang and He (2007)

CANNON BEACH PALEOTSUNAMI EXPERIMENT

Simulated tsunami inundations on1000-yr-old paleo-landscapes compared to cored tsunami deposits.

Figure from Priest et al. (2009)



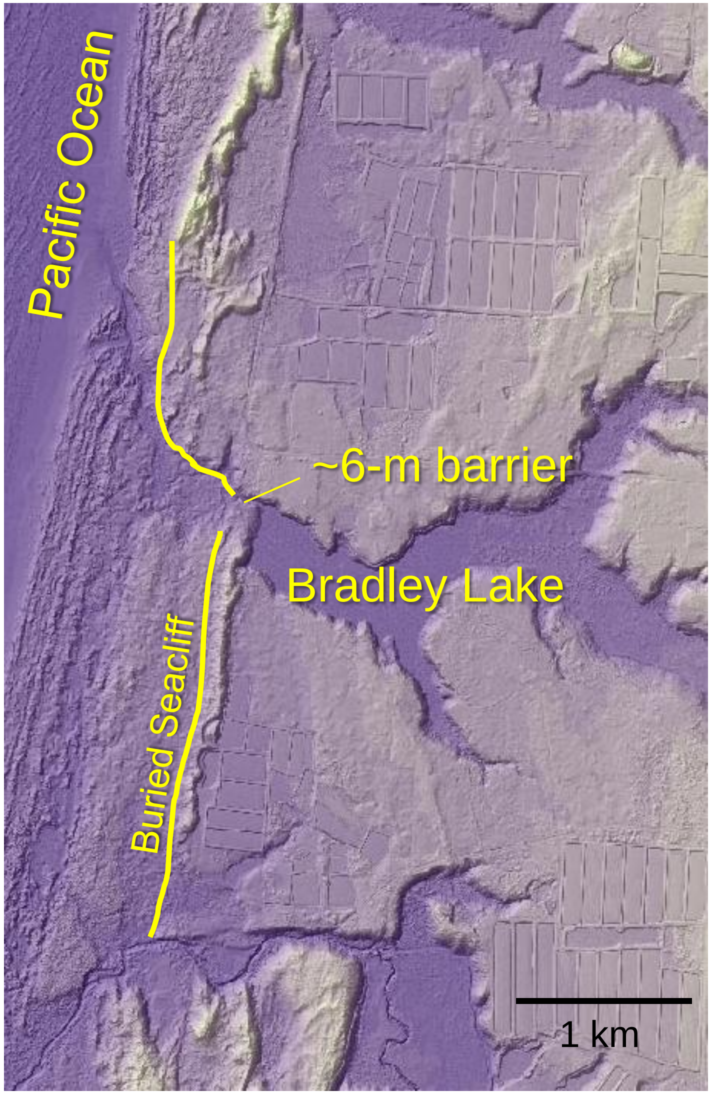
Cannon Beach Experiment RESULTS

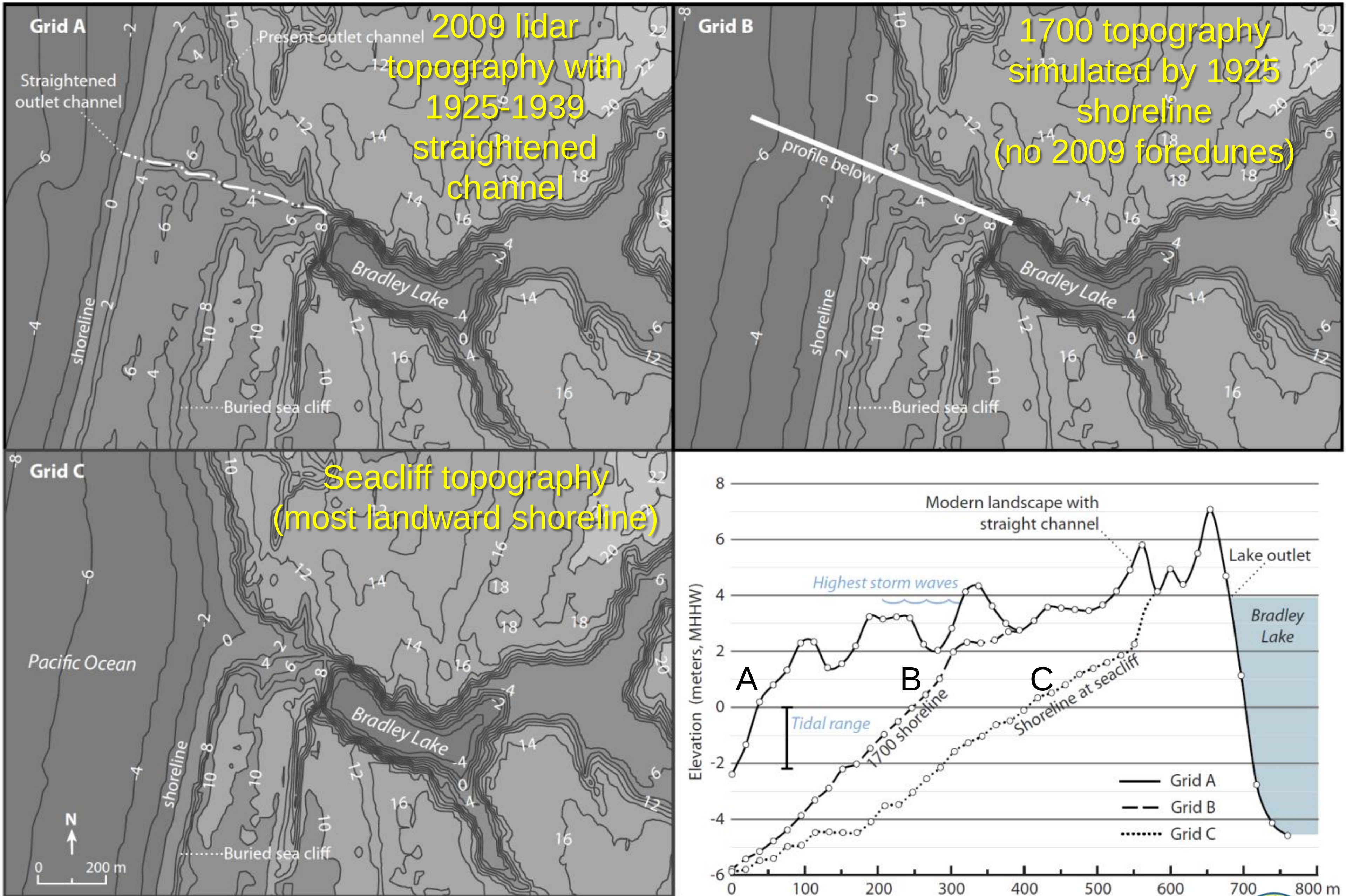
Minimum peak fault slip = ~ 14 m (splay fault) –15 m (no splay fault) to inundate past the last 3 Cascadia tsunami deposits

Bradley Lake Experiment

- Validate tsunami simulations against 4600 yrs of CSZ tsunami deposits in Bradley Lake

⁕ Simulate the ***LEAST*** tsunamis
⁕ Experimental variables:
  - Landscape
  - Sea level
  - Earthquake source

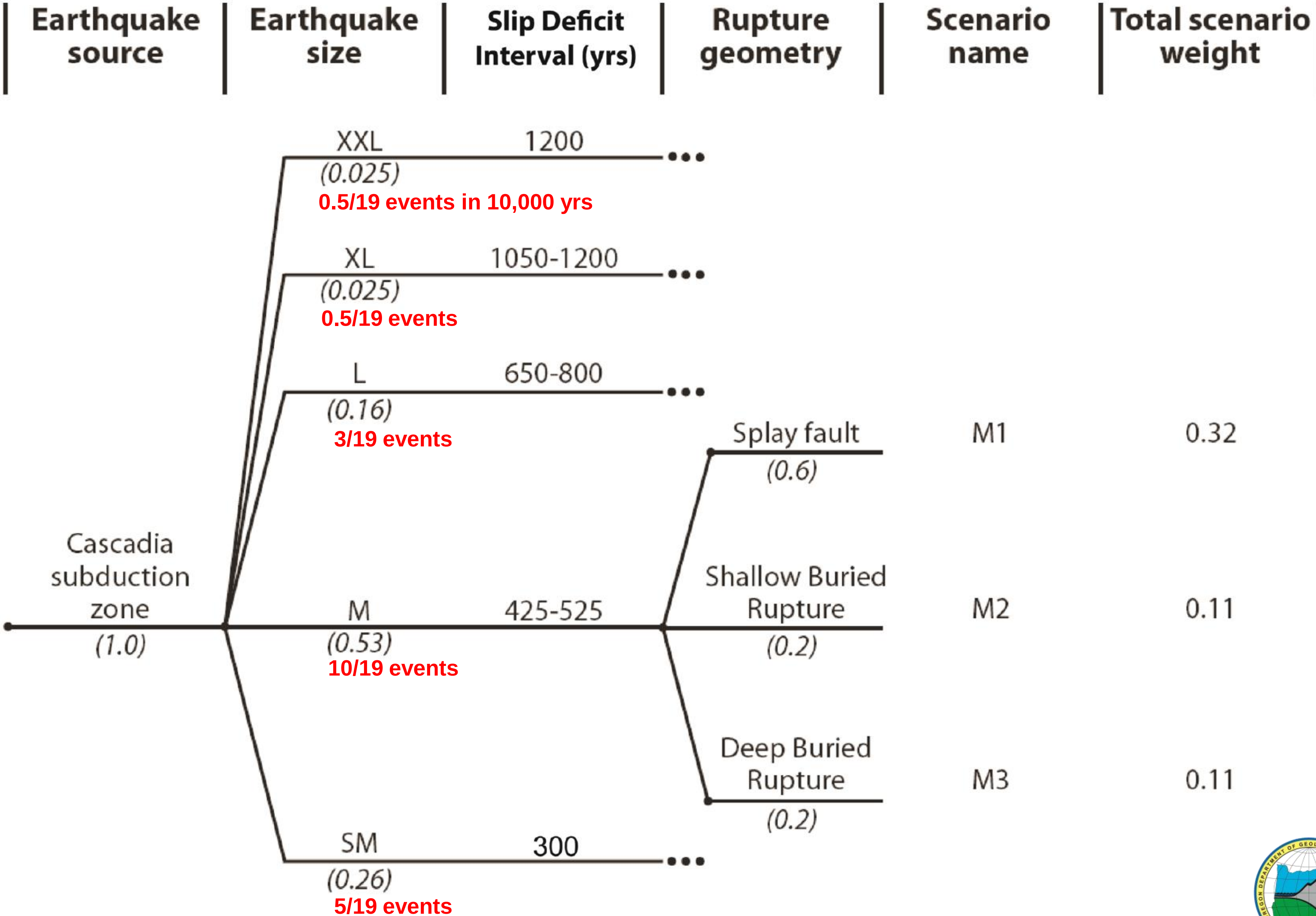



Grid A
2009 lidar topography with 1925-1939 straightened channel
Present outlet channel
Straightened outlet channel
shoreline
Bradley Lake
Buried sea cliff
Grid B
1700 topography simulated by 1925 shoreline (no 2009 foredunes)
profile below
Grid C
Seacliff topography (most landward shoreline)
Pacific Ocean
N
0
200 m
Modern landscape with straight channel
Lake outlet
Highest storm waves
Tidal range
1700 shoreline
Shoreline at seacliff
A
B
C
Elevation (meters, MHHW)
Grid A
Grid B
Grid C
0
100
200
300
400
500
600
700
800 m

Bradley Lake Experiment RESULTS

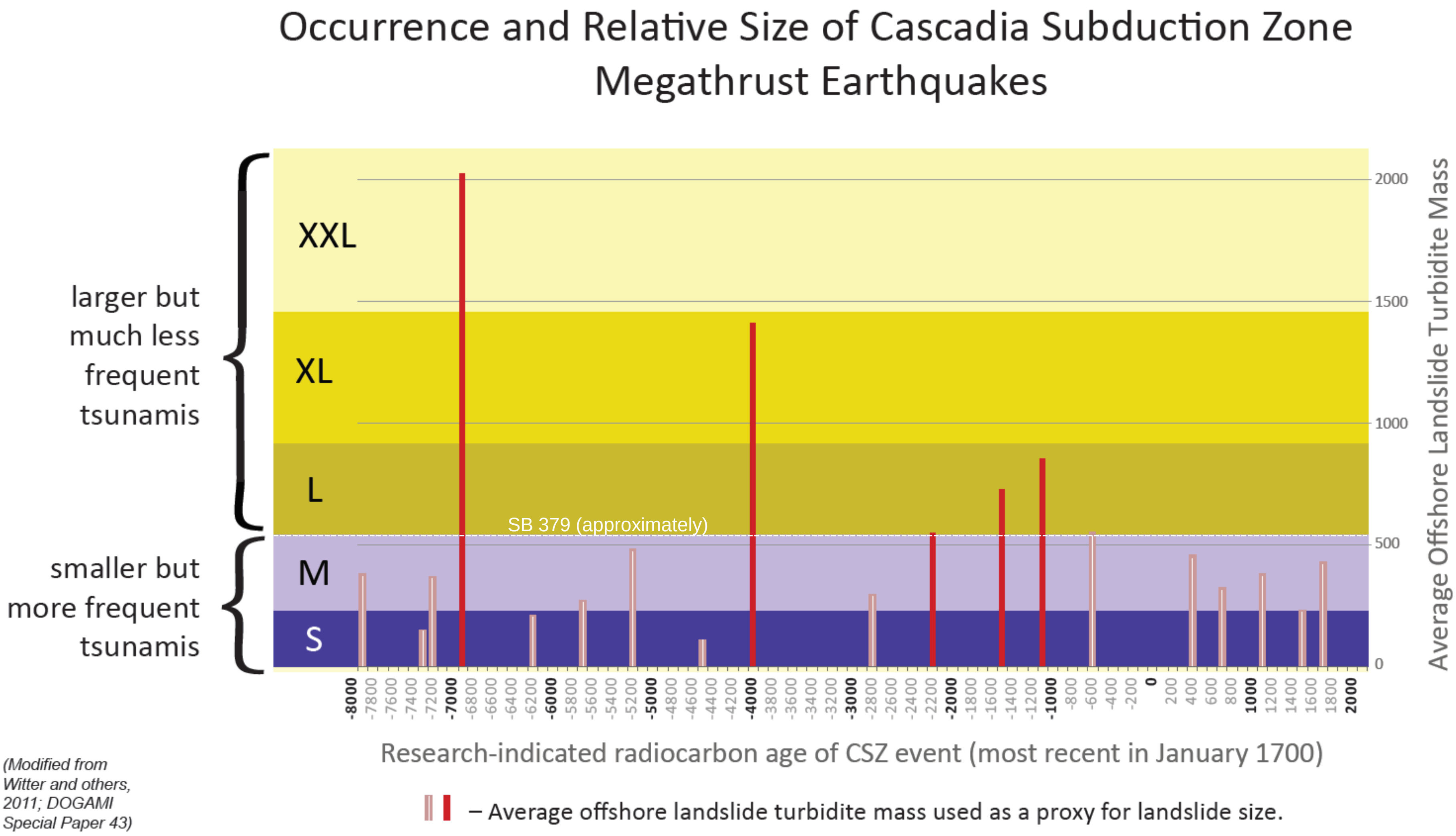
- **For AD 1700 shoreline** (contemporaneous with an "average" turbidite): Minimum peak fault slip = ~12 (splay) to 13 m (no splay) (Witter et al., 2012)
- **For most landward shoreline** (smallest tsunami able to reach lake): Minimum peak fault slip = ~8 (splay) to 9 m (no splay) (Witter et al., 2012)
- Mean recurrence of Bradley Lake tsunami sands = 380–400 yrs in last 4,600 yrs when geomorphic condition of lake effectively captured tsunami sands, according to Kelsey et al. (2005)
- Mean recurrence of turbidites directly offshore = 300-380 yrs (Priest et al., 2014)
- Mean Slip Deficit from mean turbidite recurrence = 10-13 m (at 34mm/yr convergence on CSZ)
- Mean slip deficit = minimum slip needed to get tsunamis in the lake a conclusion compatible with conclusions of segment tsunami paper of Priest et al. (2014).

LOGIC TREE FOR 15 FULL-MARGIN CASCADIA SOURCES



Modified from Priest et al. (2013)

Qualitative Explanation of Cascadia Tsunami Scenarios
shown on published tsunami inundation maps (TIMs)



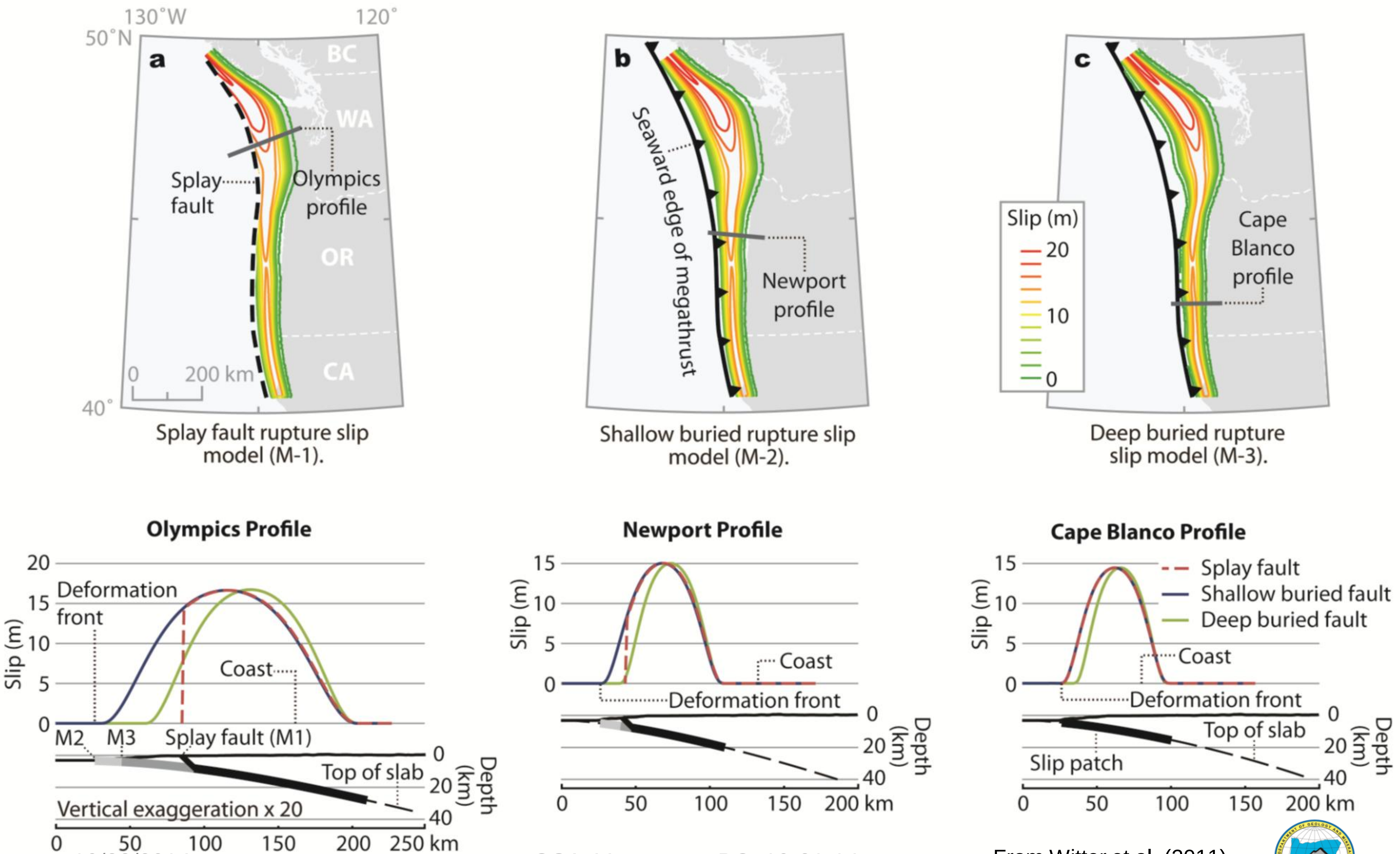
(Modified from Witter and others, 2011; DOGAMI Special Paper 43)

Cascadia Earthquake Source Parameters

Earthquake Size (weight)	Slip Deficit (yrs) [Max Slip (m)]	Fault Geometry (weight)	Earthquake Scenario	M_w	Total Weight
Extra-extra-large (1/19/2 = 0.02)	1200 [36-44]	Splay fault (0.8)	**XXL 1**	~9.1	0.02
		Shallow buried rupture (0.1)	**XXL 2**	~9.2	<0.001
		Deep buried rupture (0.1)	**XXL 3**	~9.1	<0.001
Extra-large (1/19/2 = 0.02)	1050-1200 [35-44]	Splay fault (0.8)	**XL 1**	~9.1	0.02
		Shallow buried rupture (0.1)	**XL 2**	~9.2	<0.001
		Deep buried rupture (0.1)	**XL 3**	~9.1	<0.001
Large (3/19 = 0.16)	650-800 [22-30]	Splay fault (0.8)	**L 1**	~9.0	0.13
		Shallow buried rupture (0.1)	**L 2**	~9.1	0.02
		Deep buried rupture (0.1)	**L 3**	~9.0	0.02
Medium (10/19 = 0.53)	425-525 [14-19]	Splay fault (0.6)	**M 1**	~8.9	0.32
		Shallow buried rupture (0.2)	**M 2**	~9.0	0.11
		Deep buried rupture (0.2)	**M 3**	~8.9	0.11
Small (5/19 = 0.26)	300 [9-11]	Splay fault (0.4)	**SM 1**	~8.7	0.10
		Shallow buried rupture (0.3)	**SM 2**	~8.8	0.08
		Deep buried rupture (0.3)	**SM 3**	~8.7	0.08

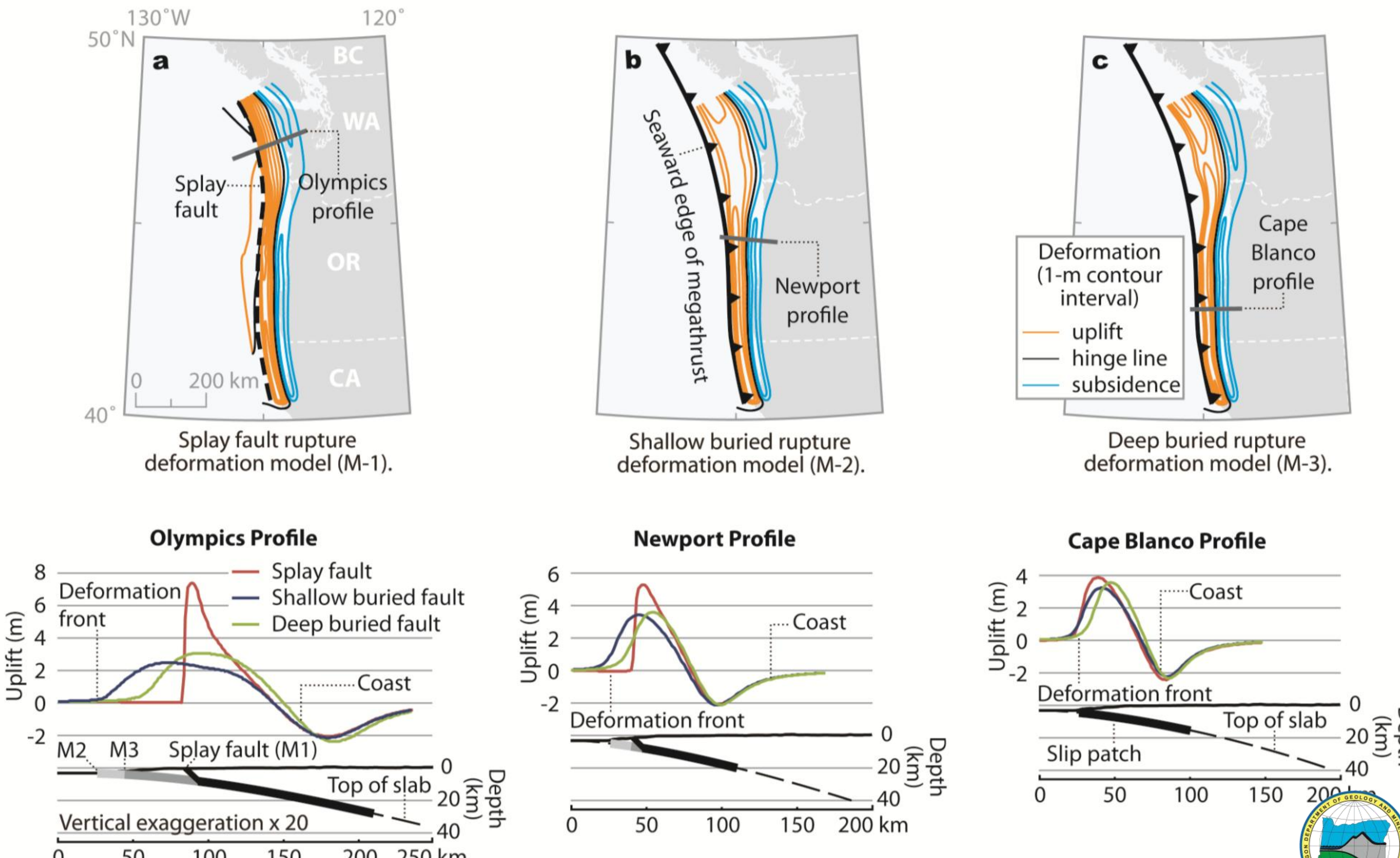
From Witter et al. (2011) with modification by Priest et al. (2013)

Earthquake Slip Models (Witter et al., 2011)



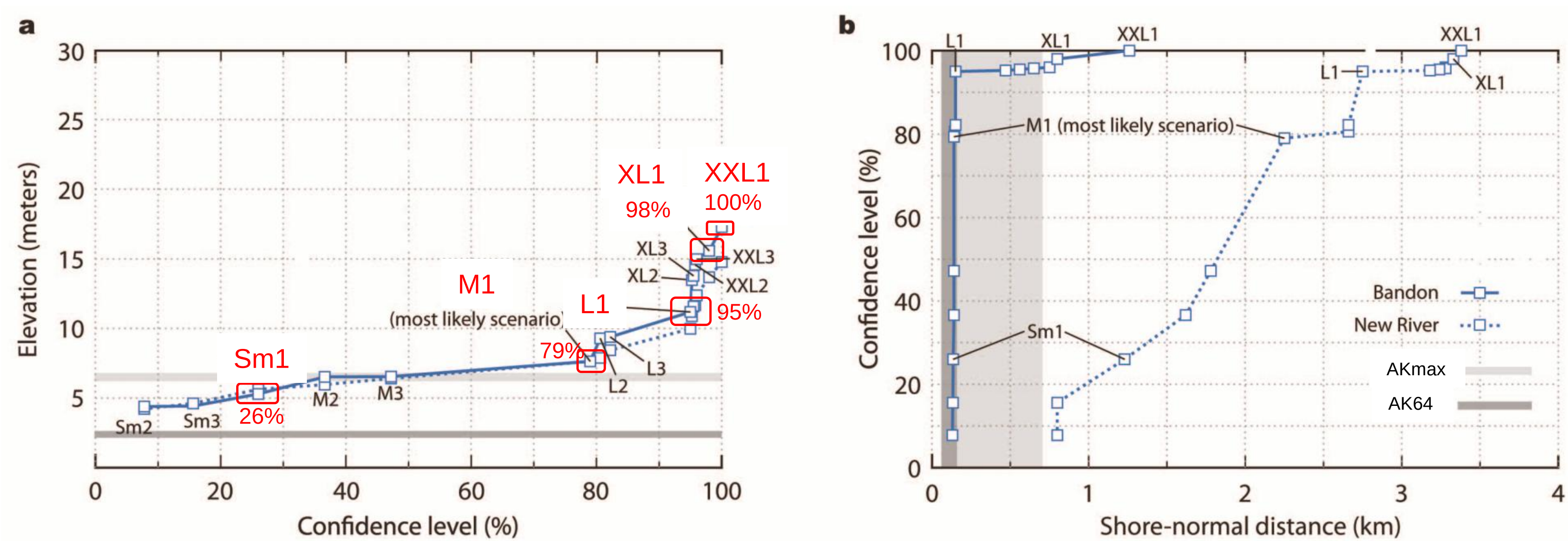
From Witter et al. (2011)

Earthquake Deformation Models



From Witter et al. (2011)

Hazard Curves for % Confidence Cascadia Elevation and Inundation Will NOT Be Exceeded



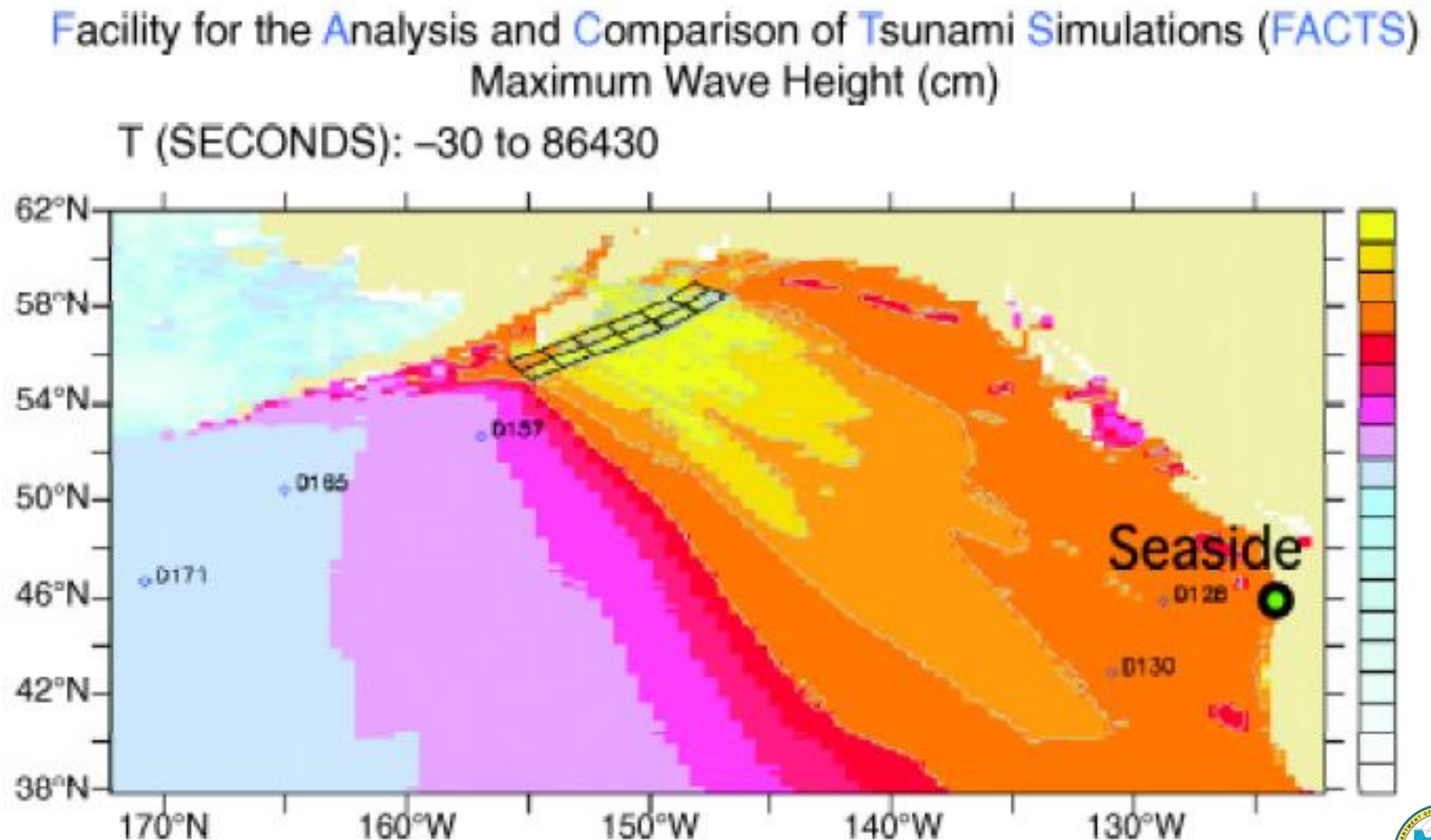
Red numbers are tsunami scenarios that were computer-simulated for the whole Oregon coast. Inundation and peak values of wave elevation, velocity, and other data were published by Oregon Dept. of Geology and Mineral Industries (www.oregontsunami.org).

Modified from Witter et al. (2011)

AKmax

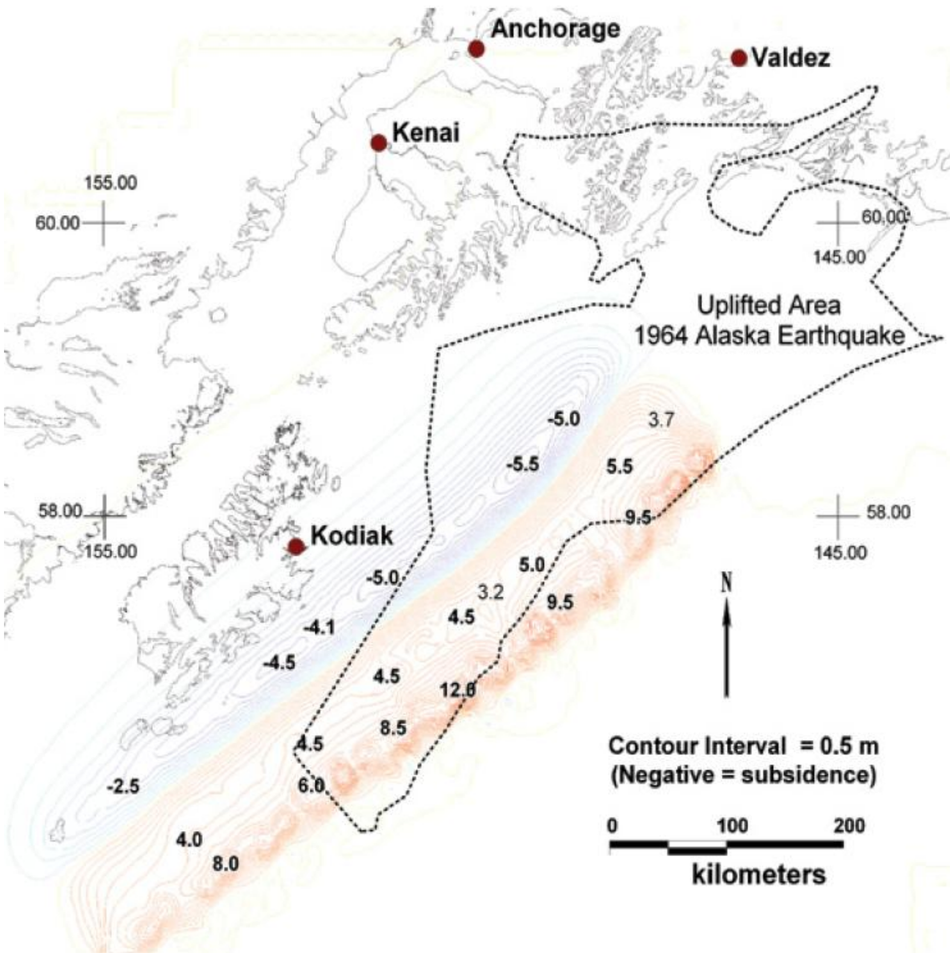
Has maximum directivity to the Oregon coast.

(Source 3 illustration from Tsunami Pilot Study Working Group (2006))

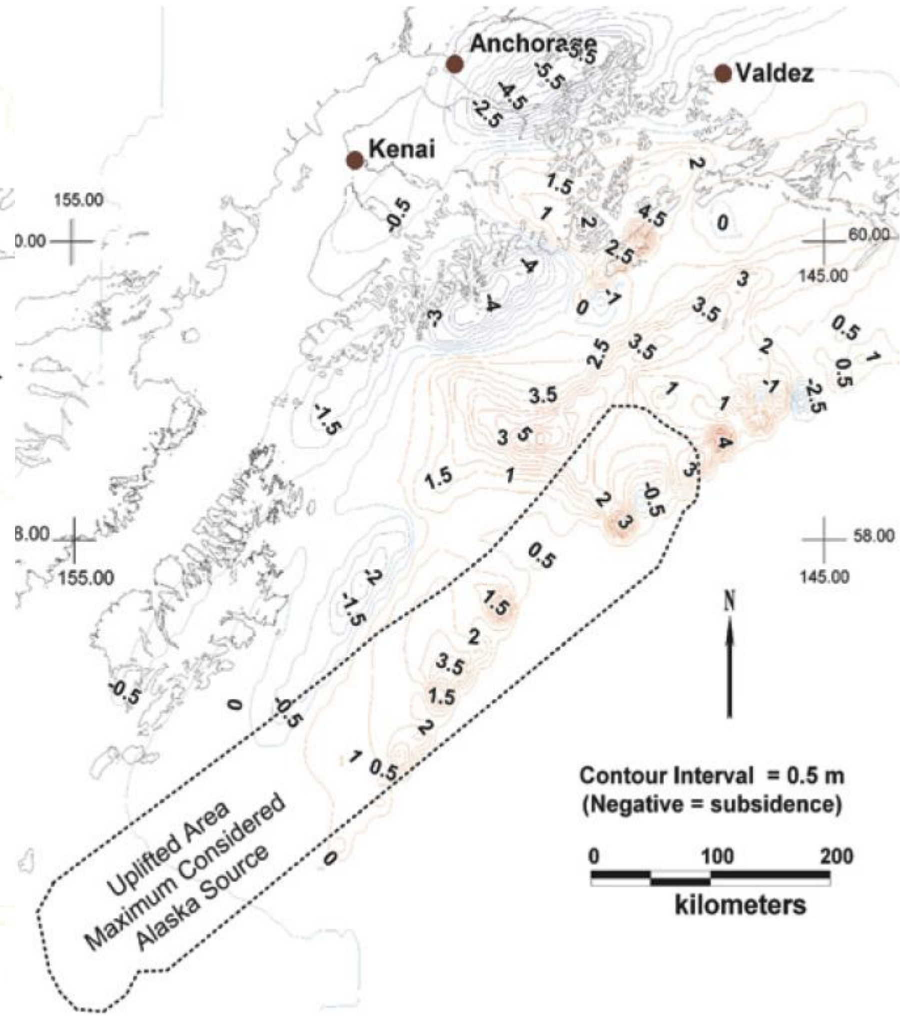


Maximum-Considered Distant Tsunami Sources for TIMs

Maximum Hypothetical (**AKmax**)

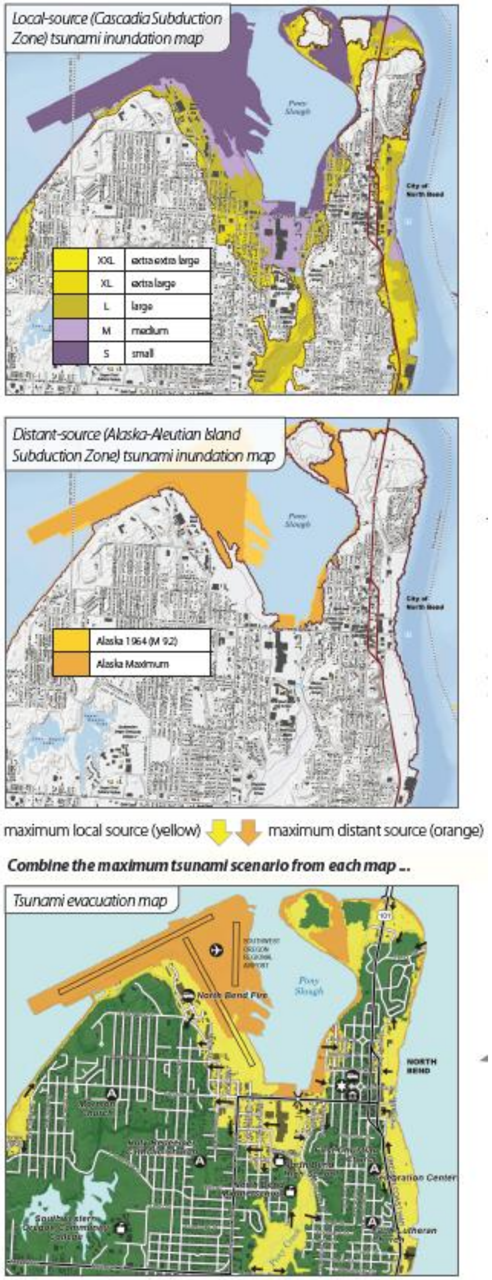


Maximum Historical (**AK64**)



From Priest et al. (2009)

INUNDATION AND EVACUATION MAP PRODUCTS



Inundation Maps (TIMs) – 7 inundations **whole coast**

- 5 Local CSZ "Tsunami T-Shirt Scenarios" (SM1, M1, L1, XL1, XXL1 – splay fault scenarios)
  - MHHW Tide
  - Coseismic subsidence taken into account
  - Maps include wave time series, inundated building exposure, and wave elevation profiles
- 2 Distant Alaska Scenarios
  - Alaska 1964
  - Alaska Max

Evacuation Brochures – 2 inundations **in towns**

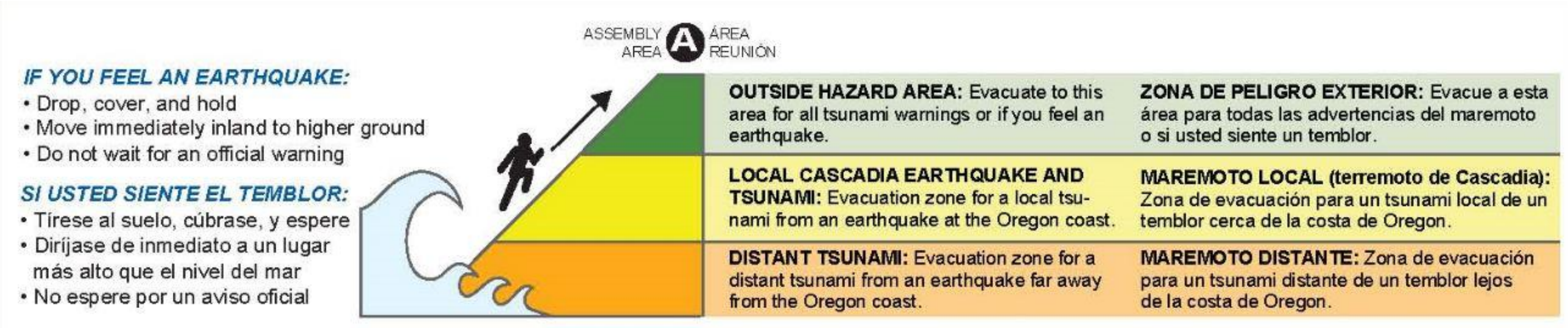
- XXL1
- Alaska Max
- Routes, preparedness information

Evacuation Mapper 2 inundations **whole coast**

- XXL1 + Alaska Max on Google type base maps
- www.oregontsunami.org

Tsunami Evacuation Map Brochure Explanation

(tested for color blindness)



www.oregontsunami.org

We cannot prevent a tsunami but we can prepare for one.

Oregon Tsunami Clearinghouse

Home | Coastal Residents | Visitors | Boaters | Kids & Teachers | Community Planners | Scientists

Frontpage Evacuation Zone Map Viewer Evacuation Brochures Regulatory Maps Resource Library

MAPPER

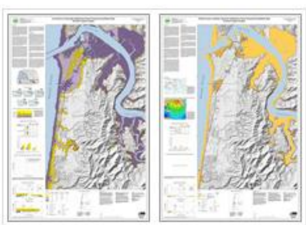
Is your family prepared for disaster?

Tsunami Evacuation Zone Map Viewer

Search by address or coastal area.
web map | iPhone app | Android app

Tsunami Evacuation Brochures

For coastal communities. Fact Sheet



Tsunami Inundation Maps (TIM Series)

Maps incorporating all the best tsunami science available today. Fact Sheet

Tsunami Regulatory Maps

Official maps for implementation of ORS 455.446 and 455.447.

Which type of tsunami map is right for you?

TsunamiReady, TsunamiPrepared News

» *Without Warning*, a new comic by OEM and Darkhorse Comics

» June 2014: "Tsunami! What Oregon Boat Owners Need to Know" PDF brochure now available.

Coastal Residents

What to watch for and how to prepare. More »

Visitors

What to do before and after you

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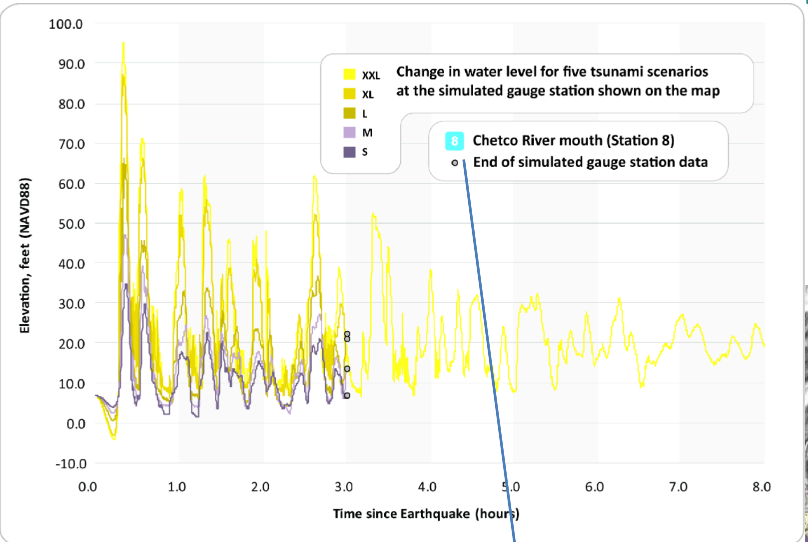
Tsunami news around the web

Underwater landslide may have
Science AAAS
About a quarter of the tsunami's 18,000 victims died in those ports, yet experts have struggled to find a satisfactory explanation for the exceptional inundation that killed them. Seismologist Kenji Satake of the University of Tokyo's Earthquake ...
Related Articles »

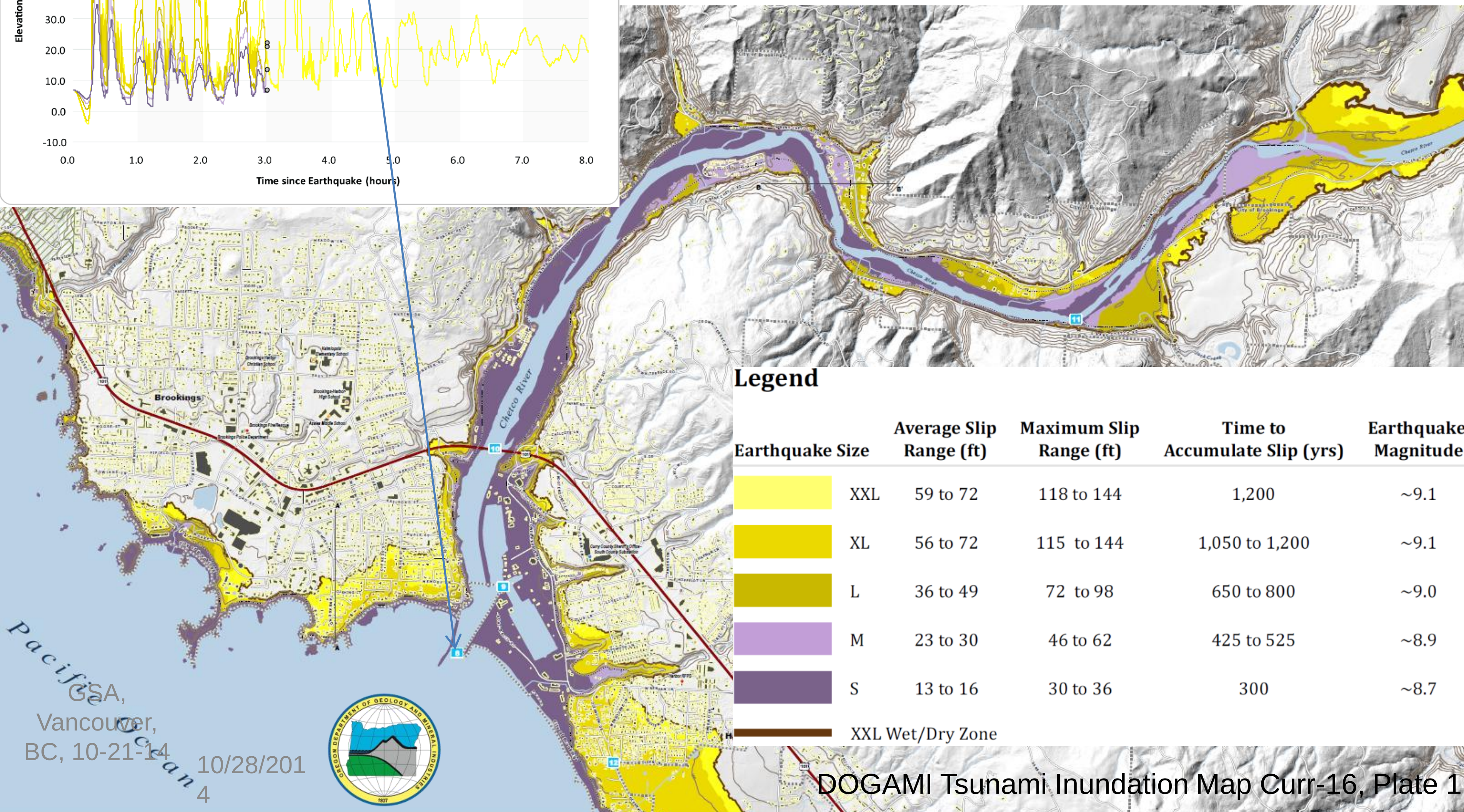
Indian Ocean region vulnerable
Deccan Chronicle
Using sand deposited in the lagoon during the 2004 Indian Ocean tsunami and seven older paleo-tsunami deposits as proxies for large earthquakes in the region, the scientists reconstructed the timeline for mega-earthquakes along the Indian Ocean's plate ...
Related Articles »

The Butterfly Effect: Predicting
MIT Technology Review
That, in turn, would allow for pragmatic actions to be taken before the metaphoric tsunami

Tsunami Inundation Map (TIM) - Local Cascadia Tsunamis



Shows Cascadia tsunami arrival at Brookings, OR **~18 minutes**
Base map is lidar-derived shaded relief.



Legend

Earthquake Size		Average Slip Range (ft)	Maximum Slip Range (ft)	Time to Accumulate Slip (yrs)	Earthquake Magnitude
	XXL	59 to 72	118 to 144	1,200	~9.1
	XL	56 to 72	115 to 144	1,050 to 1,200	~9.1
	L	36 to 49	72 to 98	650 to 800	~9.0
	M	23 to 30	46 to 62	425 to 525	~8.9
	S	13 to 16	30 to 36	300	~8.7
	XXL Wet/Dry Zone				

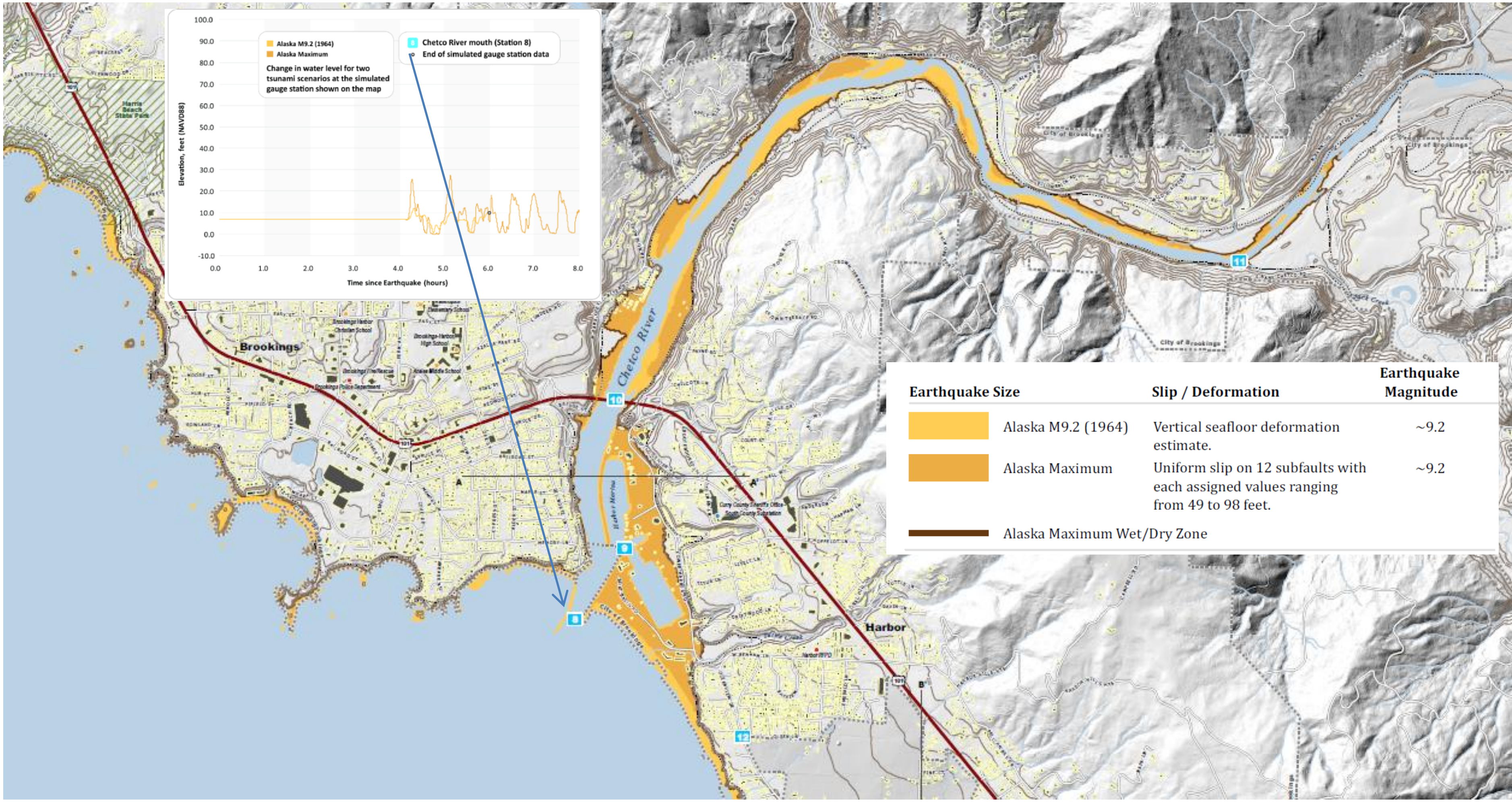
GSA, Vancouver, BC, 10-21-14

10/28/2014

DOGAMI Tsunami Inundation Map Curr-16, Plate 1

Tsunami Inundation Map (TIM) - Distant Tsunamis

Brookings, Oregon



DOGAMI Tsunami Inundation Map Curr-16, Plate 2