New Oregon Tsunami Simulation Scenarios, Published Data, and Probable Effect on the Oregon Building Code

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Presentation to the workshop on

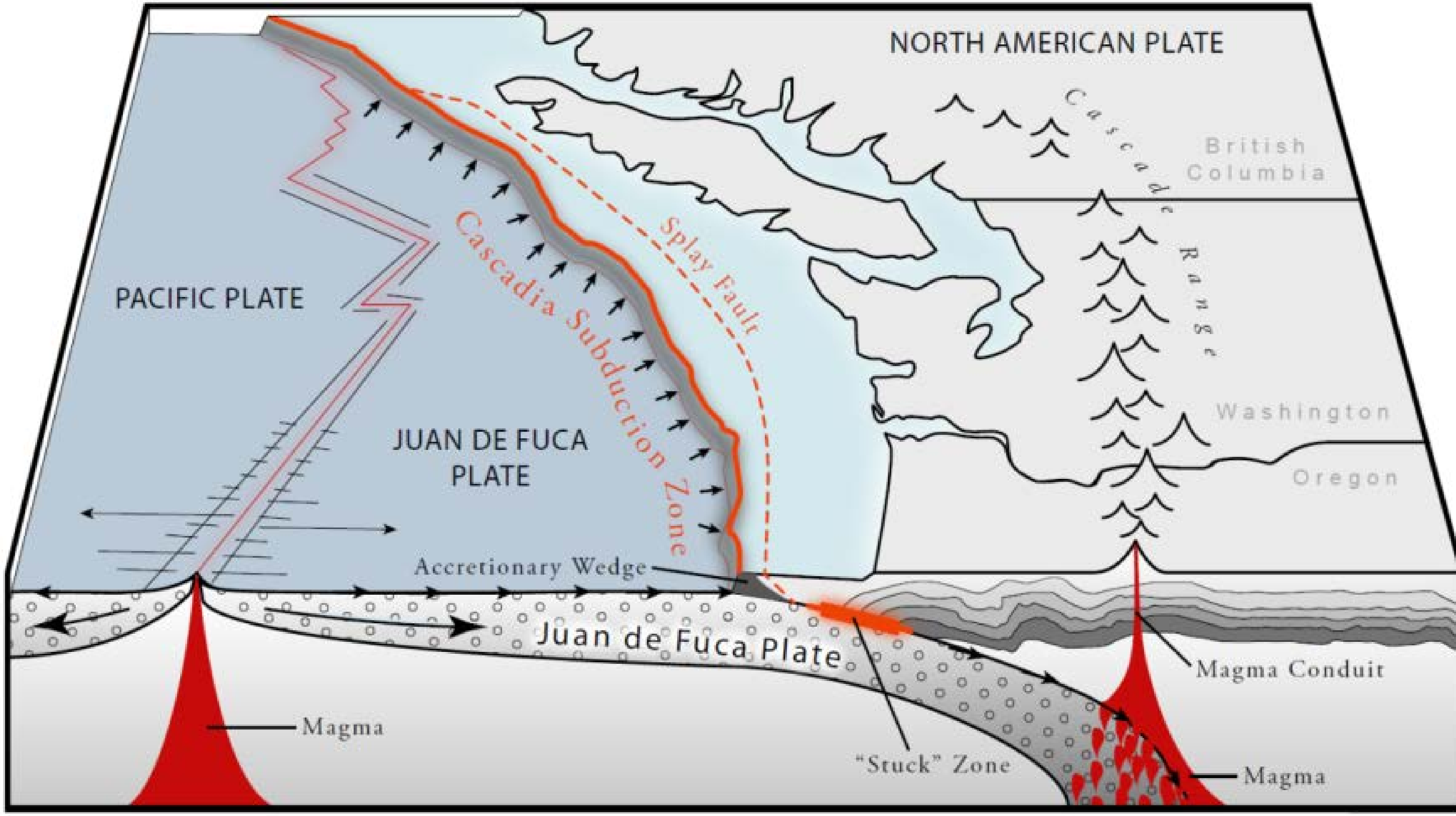
Designing for Tsunamis: New Oregon Data & Anticipated Changes to the Building Code

Portland State Office Building, Portland, Oregon

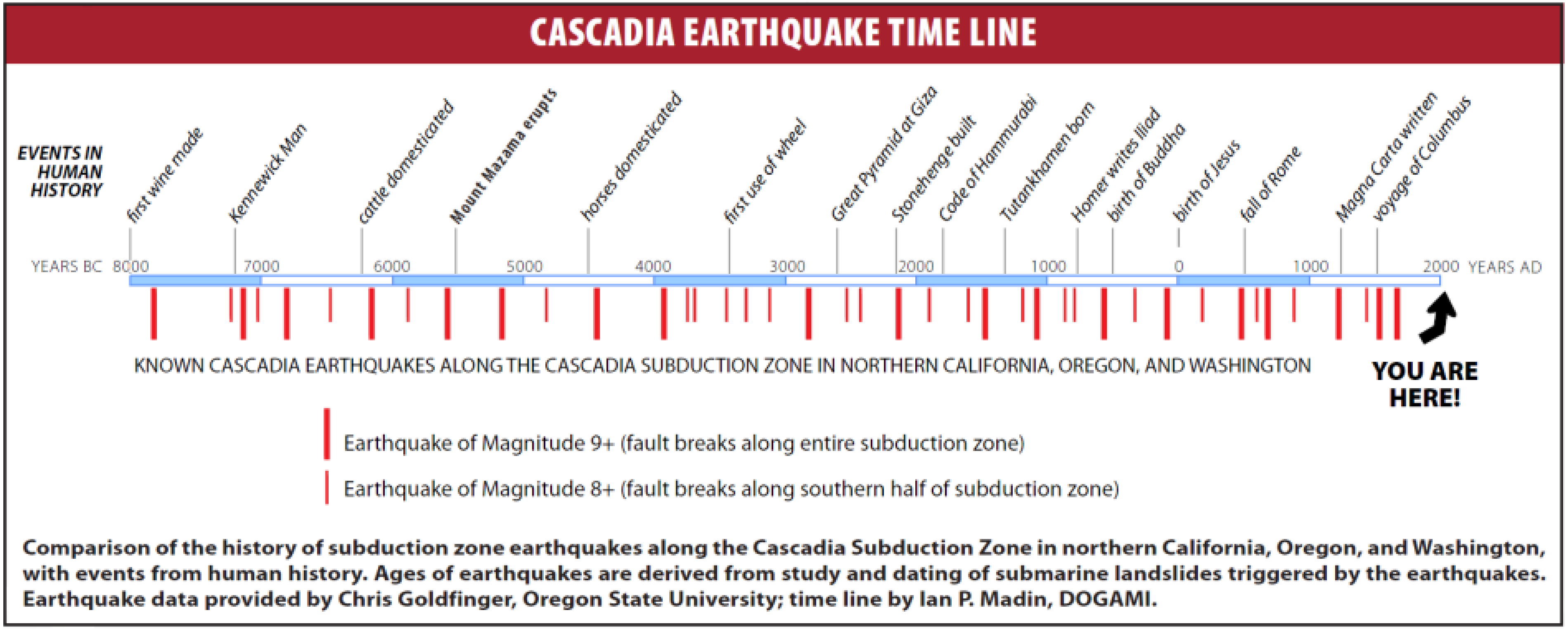
May 18, 2015

Cascadia Subduction Zone (CSZ)

North American Plate Overrides Juan de Fuca Plate Along
Cascadia Subduction Zone at a rate of 1.5 inches/year



What does the 10,000 year history of ~40 great Cascadia earthquakes and tsunamis mean for probabilistic tsunami hazard analysis (PTHA)?

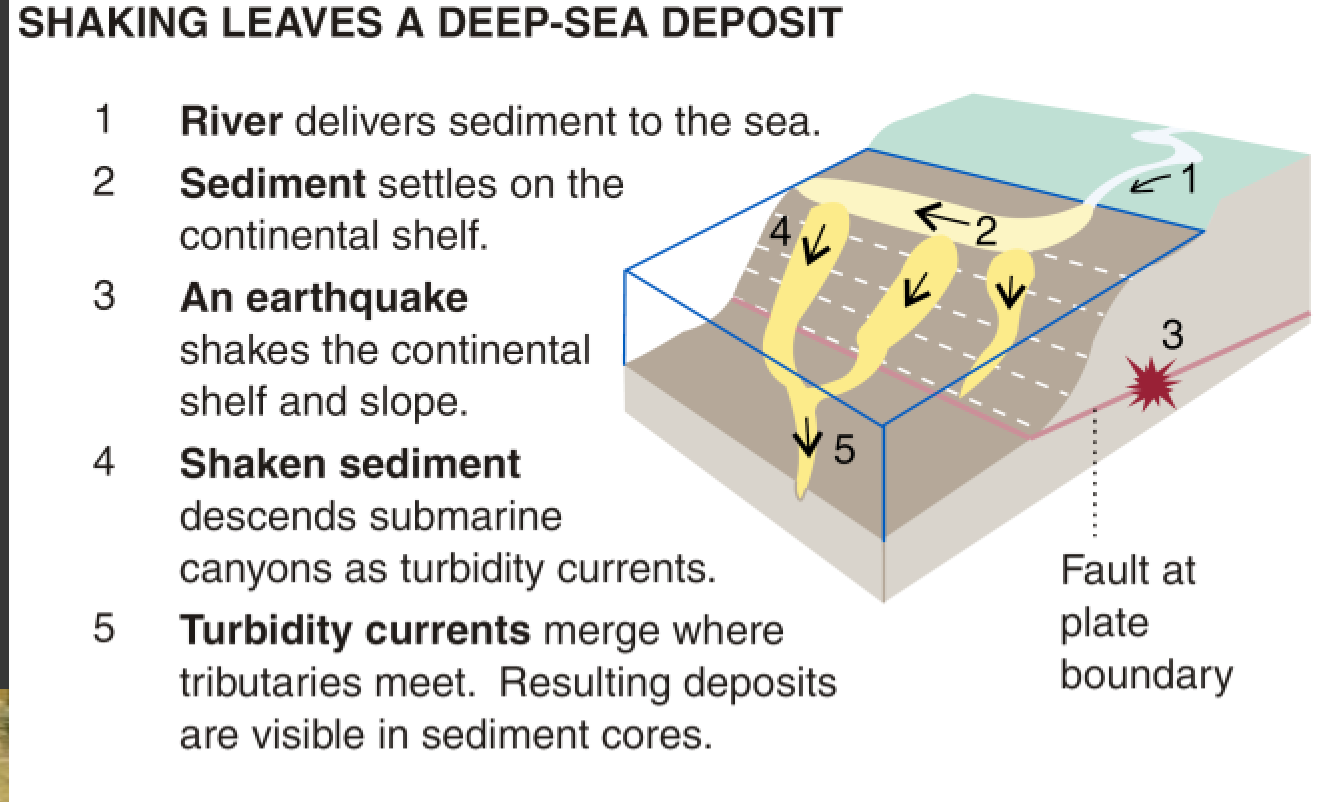


The last big Cascadia earthquake and *local* tsunami in the Northwest was January 26, 1700 at ~9:00 PM.

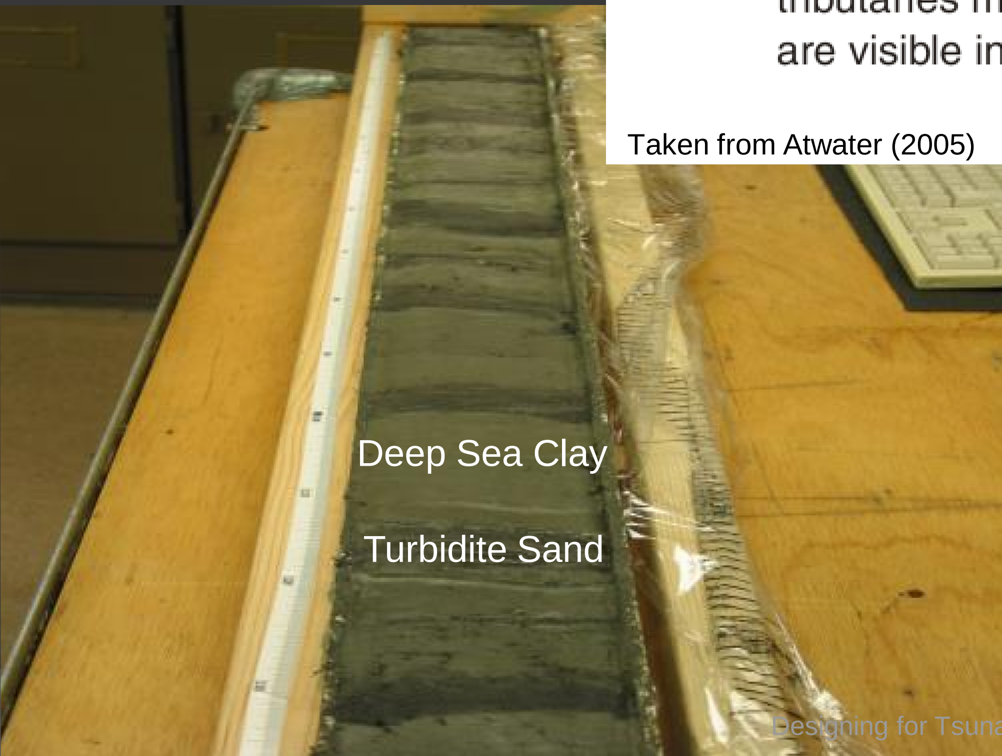
(Satake et al., 2003, Journ. Geophys. Res., v 108, no. B11, p. 2535.)

Turbidites in a deep sea core.

(picture provided by Chris Goldfinger, 2010)

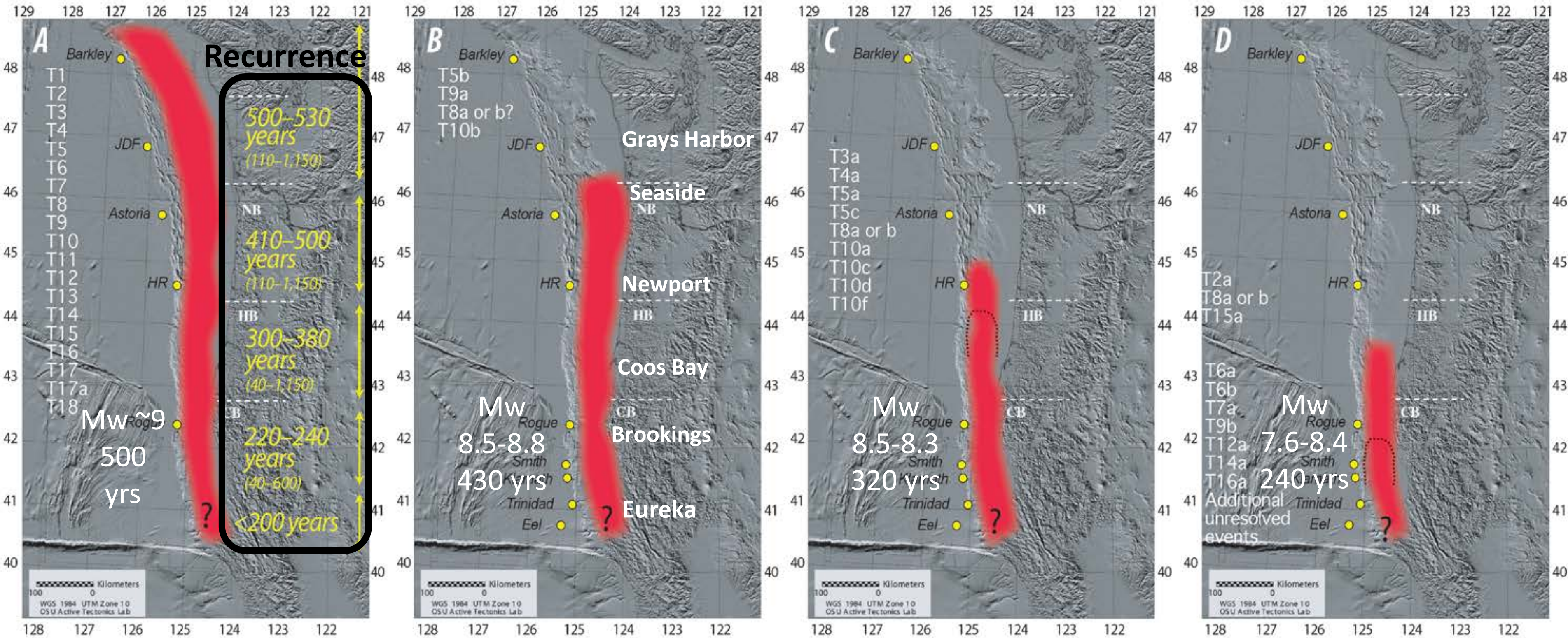


Taken from Atwater (2005)



Cascadia Fault Rupture Lengths from Turbidite Data
~40 earthquakes over the last 10,000 years

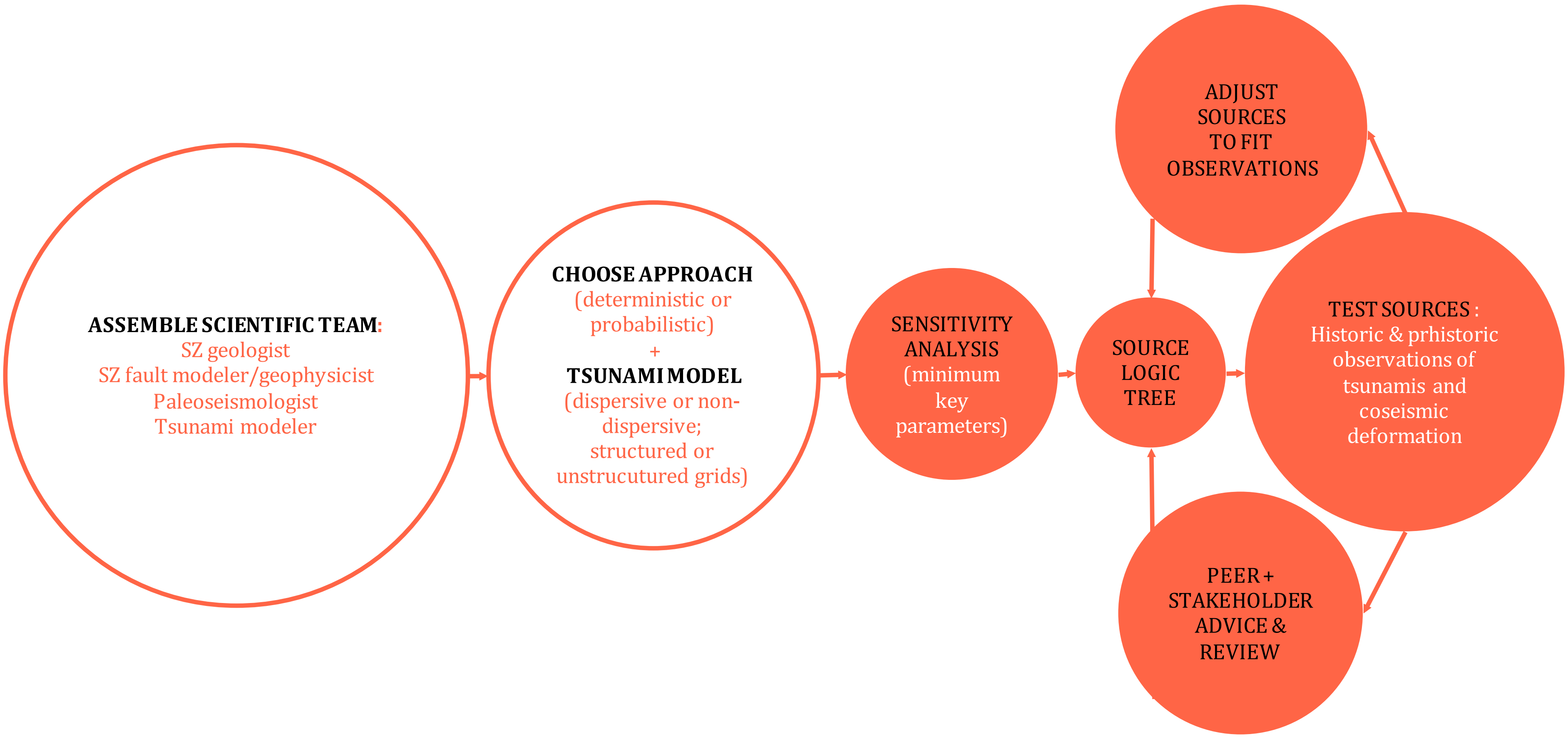
19 earthquakes | **4** earthquakes | **7** earthquakes | **10** earthquakes



CONCLUSION: **Recurrence of tsunamis ≥~200 yrs dominated by Cascadia sources.**

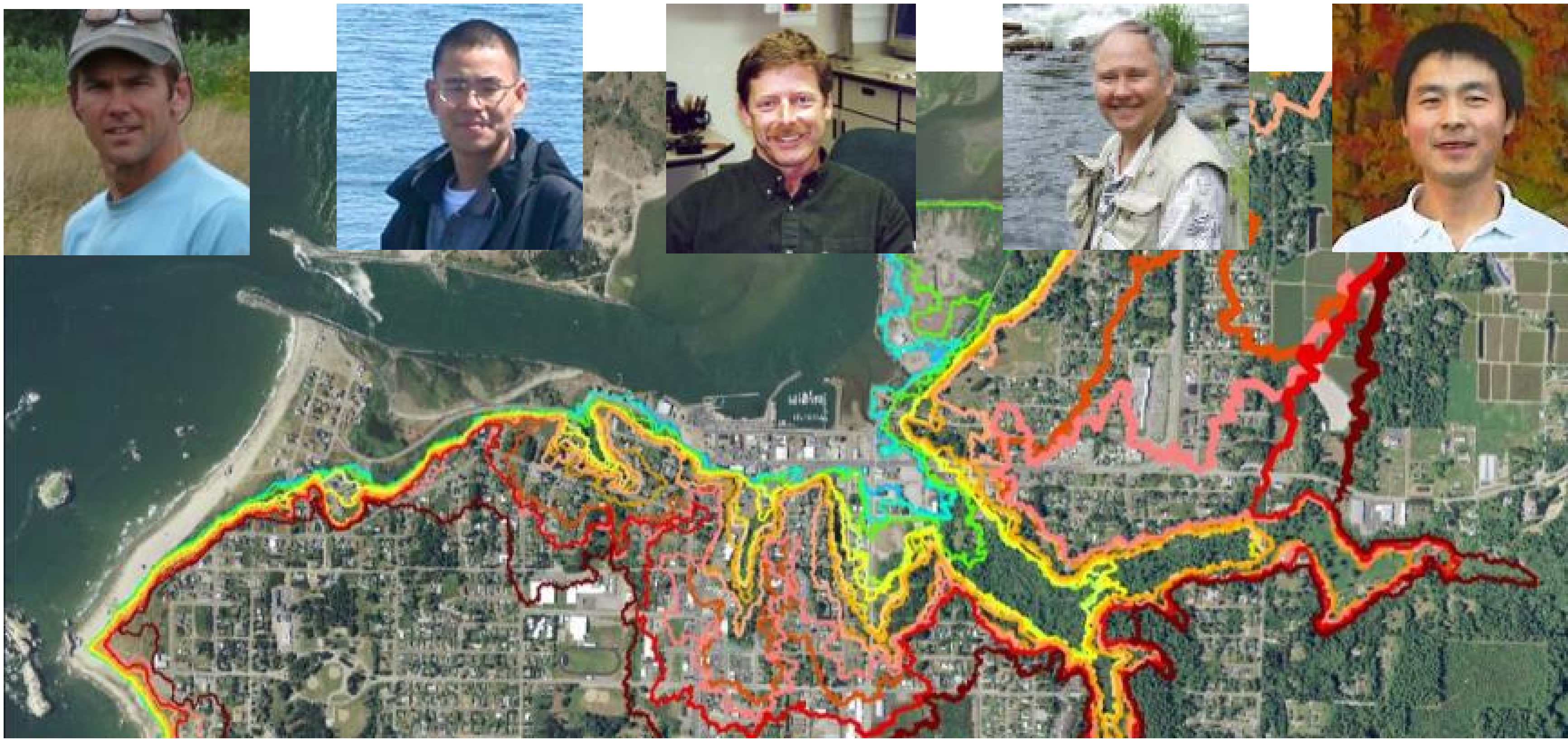
Illustration modified from Goldfinger et al. (2012)

Tsunami Hazard Assessment Focused on (1) Defining Cascadia Sources and (2) Highly Refined Tsunami Simulations



TSUNAMI HAZARD ASSESSMENT
The 2007-2013 Scientific Team

Rob Witter | Joseph Zhang | Chris Goldfinger | George Priest | Kelin Wang



CMOP
Center for Coastal Margin Observation & Prediction

COAS
College of Oceanic and Atmospheric Sciences

THE QUEST FOR SLIP

Tsunami height is mainly determined by:

1) Peak coseismic fault slip

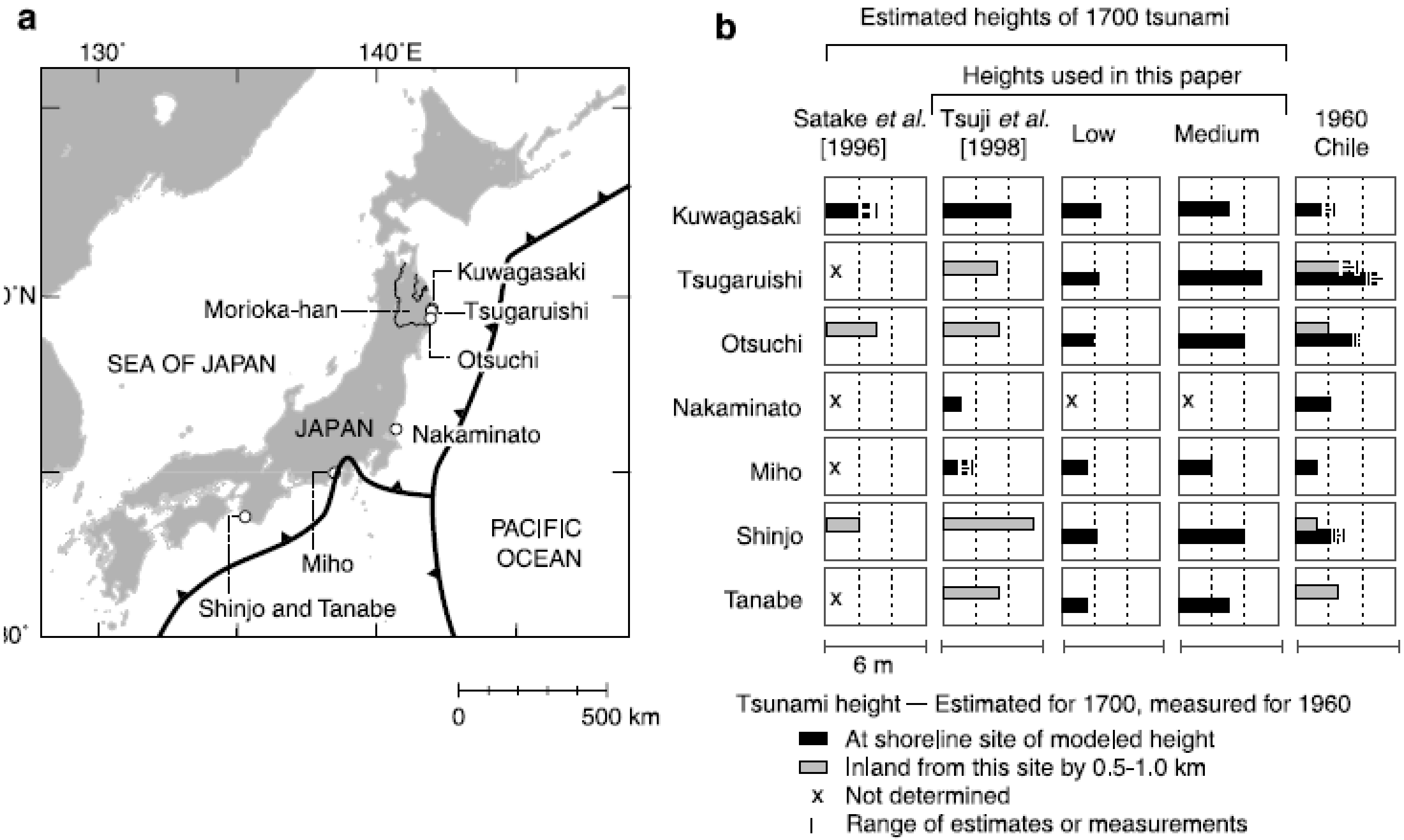
and

2) How slip deforms the ocean floor directly offshore

Step 1 - Ground Truth

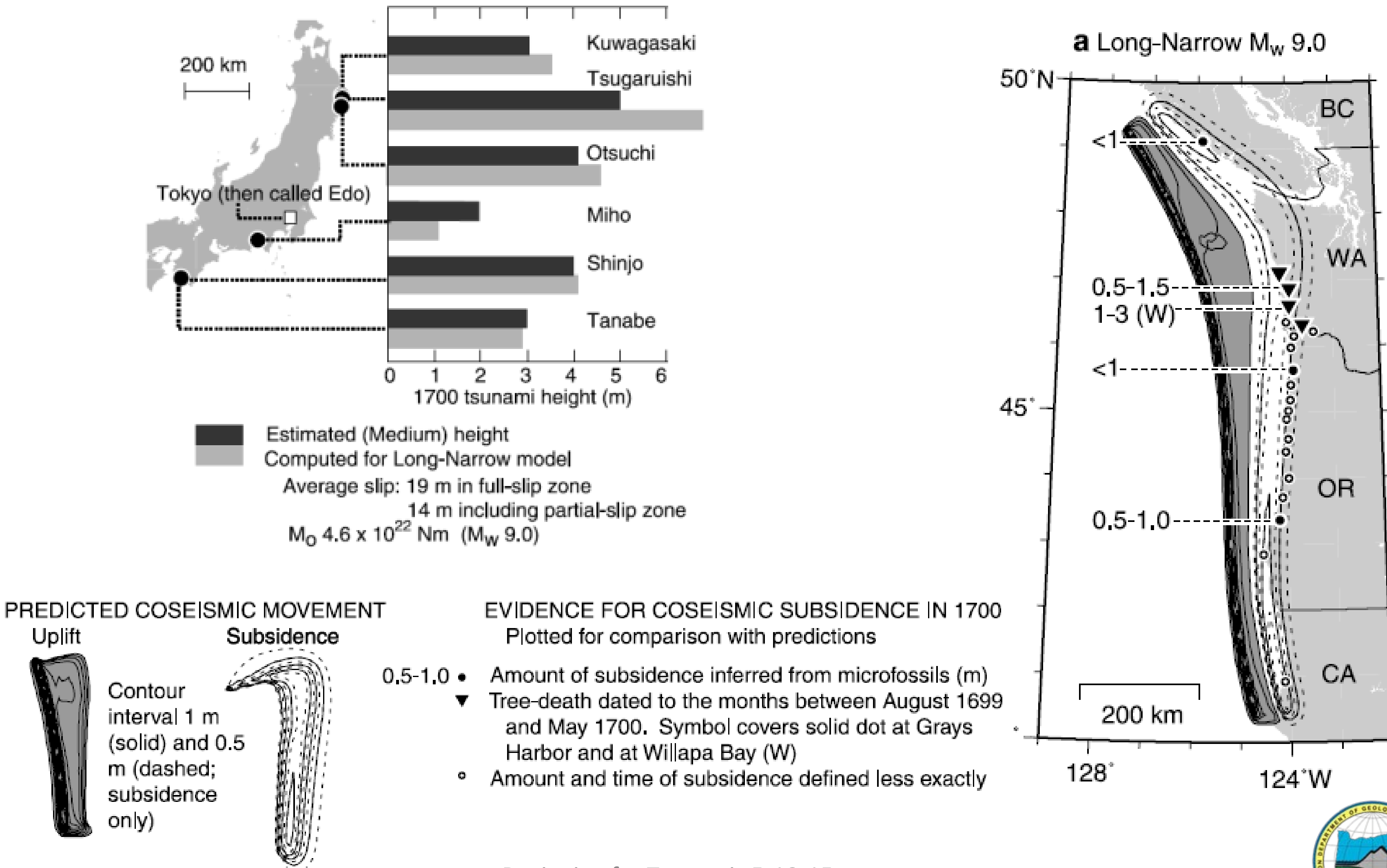
Determine minimum peak slip needed to account for paleotsunami deposits and historical observations of the AD 1700 tsunami using reasonable Cascadia seismic source models.

AD 1700 Cascadia Tsunami in Japan (up to **~5 m or ~16 ft** at the shoreline)

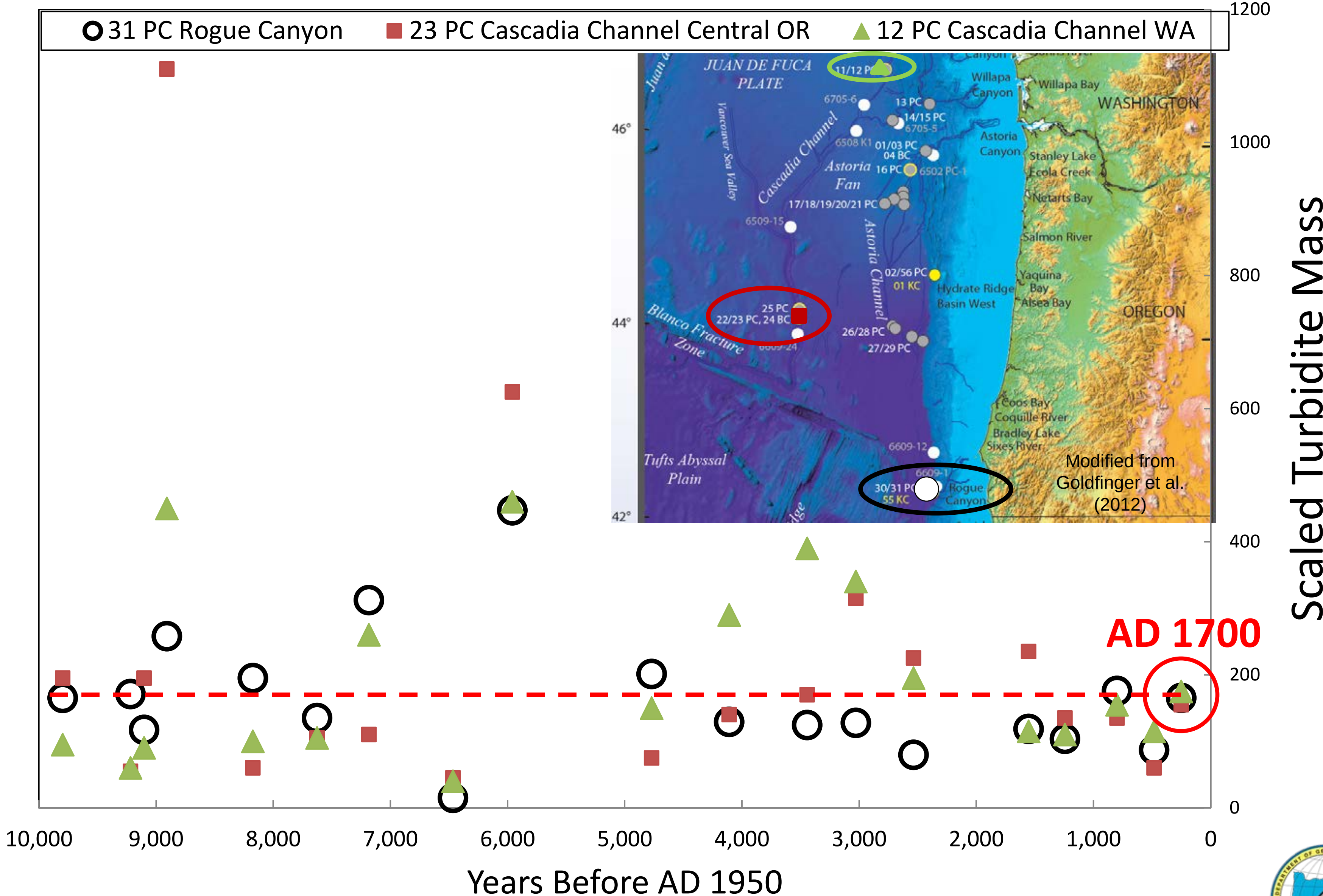


From Satake et al. (2003) JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. B11, 2535, doi:10.1029/2003JB002521

RESULTS of Satake et al. (2003) for AD1700 CSZ Earthquake = **<u>19 m Slip</u>** (**<u>~530 yrs</u>** of slip deficit release)



How does size of the **AD 1700** earthquake compare to the other 19 full-margin Cascadia earthquakes? Inference from turbidite masses:



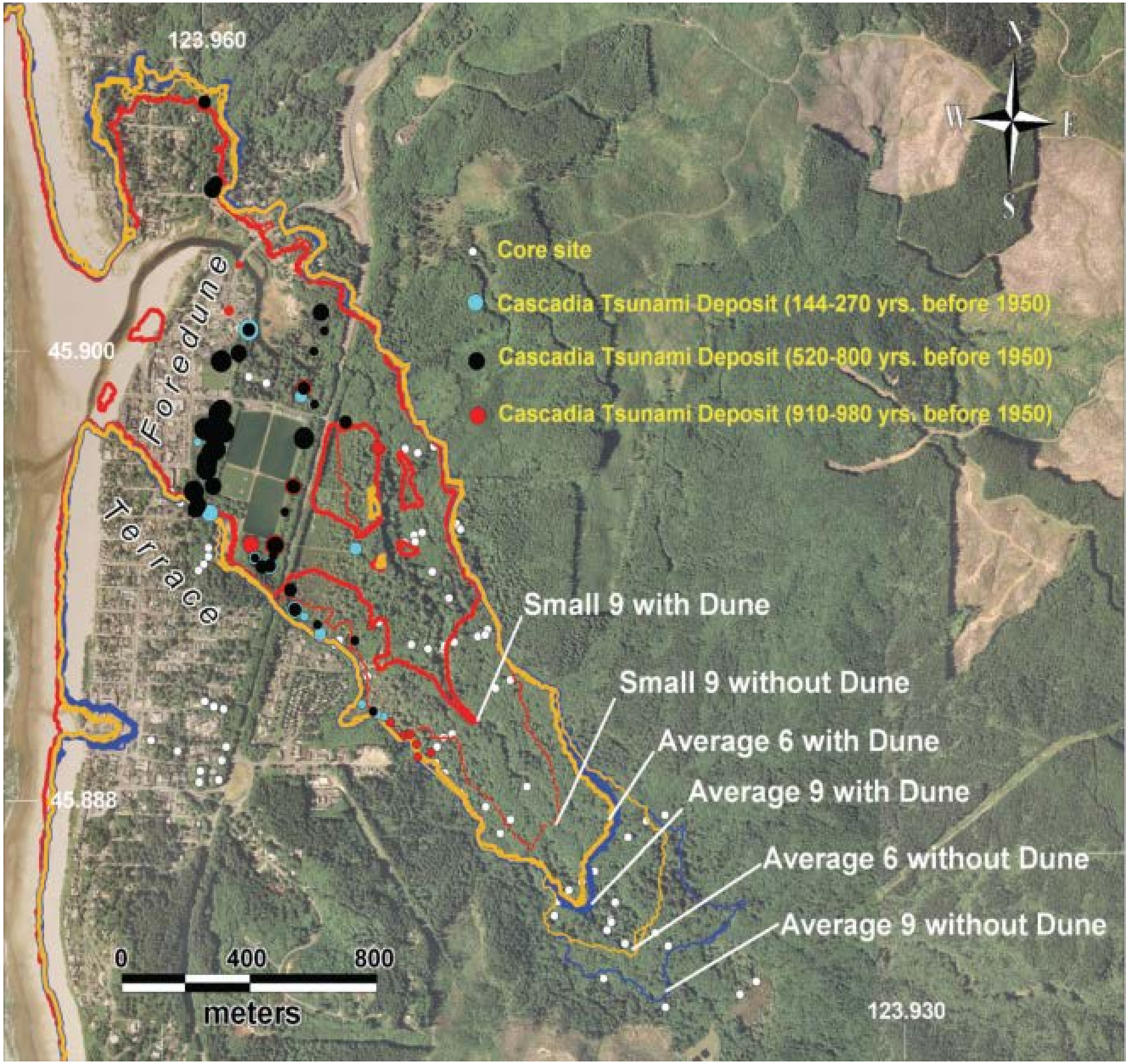
Conclusions from Observations of AD 1700 Earthquake:

- “Average” of 19 full-margin events over 10,000 yrs
- ~19 m slip (~530 yrs slip deficit release)

CANNON BEACH PALEOTSUNAMI EXPERIMENT

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

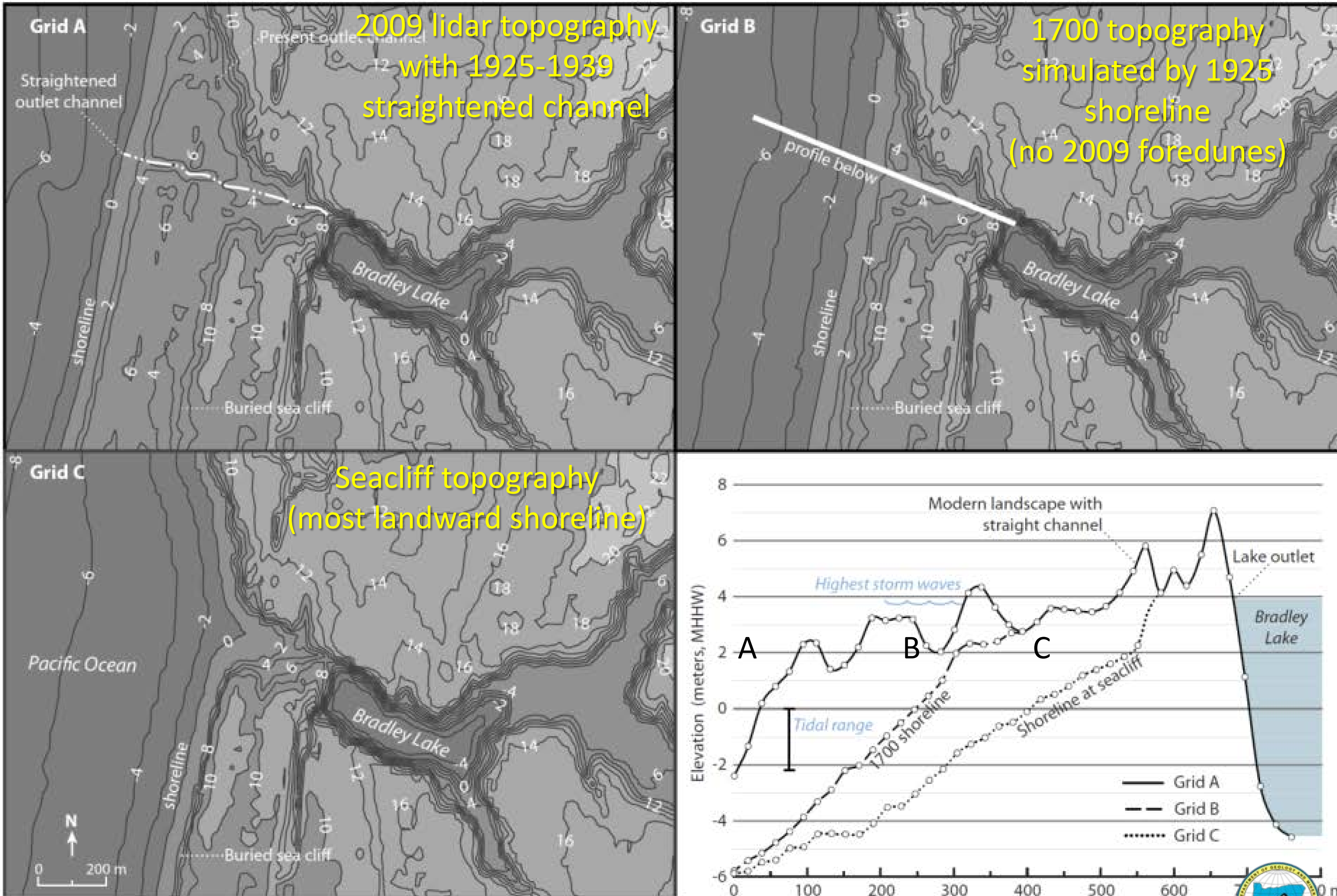
Figure from Priest et al. (2009a)



RESULTS
Cannon Beach Experiment

Minimum peak fault slip = ~ 14 m (splay fault) –15 m (no splay fault)
(389-416 yrs slip deficit release)
to inundate past the last 3 Cascadia tsunami deposits

Bradley Lake Experiment



RESULTS: Bradley Lake Experiment

- For AD 1700 shoreline (contemporaneous with an "average" turbidite):

  Minimum peak fault slip = ~12 to 13 m (Witter et al., 2012)

  360-400 yrs slip deficit
- For most landward shoreline (smallest tsunami able to reach lake):

  Minimum peak fault slip = ~8 to 9 m (Witter et al., 2012)

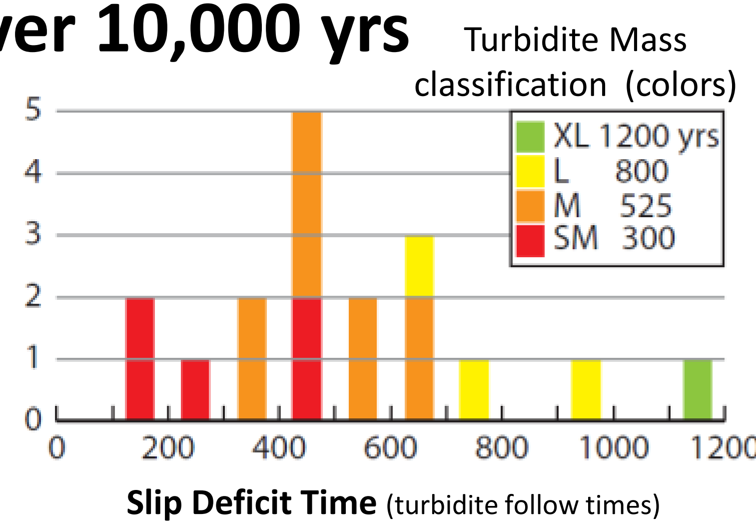
  260-290 yrs slip deficit
- Mean recurrence of Bradley Lake tsunami sands = 380–400 yrs in last 4,600 yrs when geomorphic condition of lake effectively captured tsunami sands, according to Kelsey et al. (2005)
- Mean recurrence of turbidites directly offshore = 300-380 yrs (Priest et al., 2014)
- Mean 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).

CONCLUSIONS from Paleoseismic Observations:

- AD 1700 tsunami was an average event and the estimated **uniform slip** of **19 m (530 yrs slip deficit release)** from Japan tsunami height is consistent with **minimum peak slip** of ~**14-15 m** at Cannon Beach and ~**12-13 m** at Bradley Lake.
- ~**500+/-150 yrs slip deficit** corresponds to:

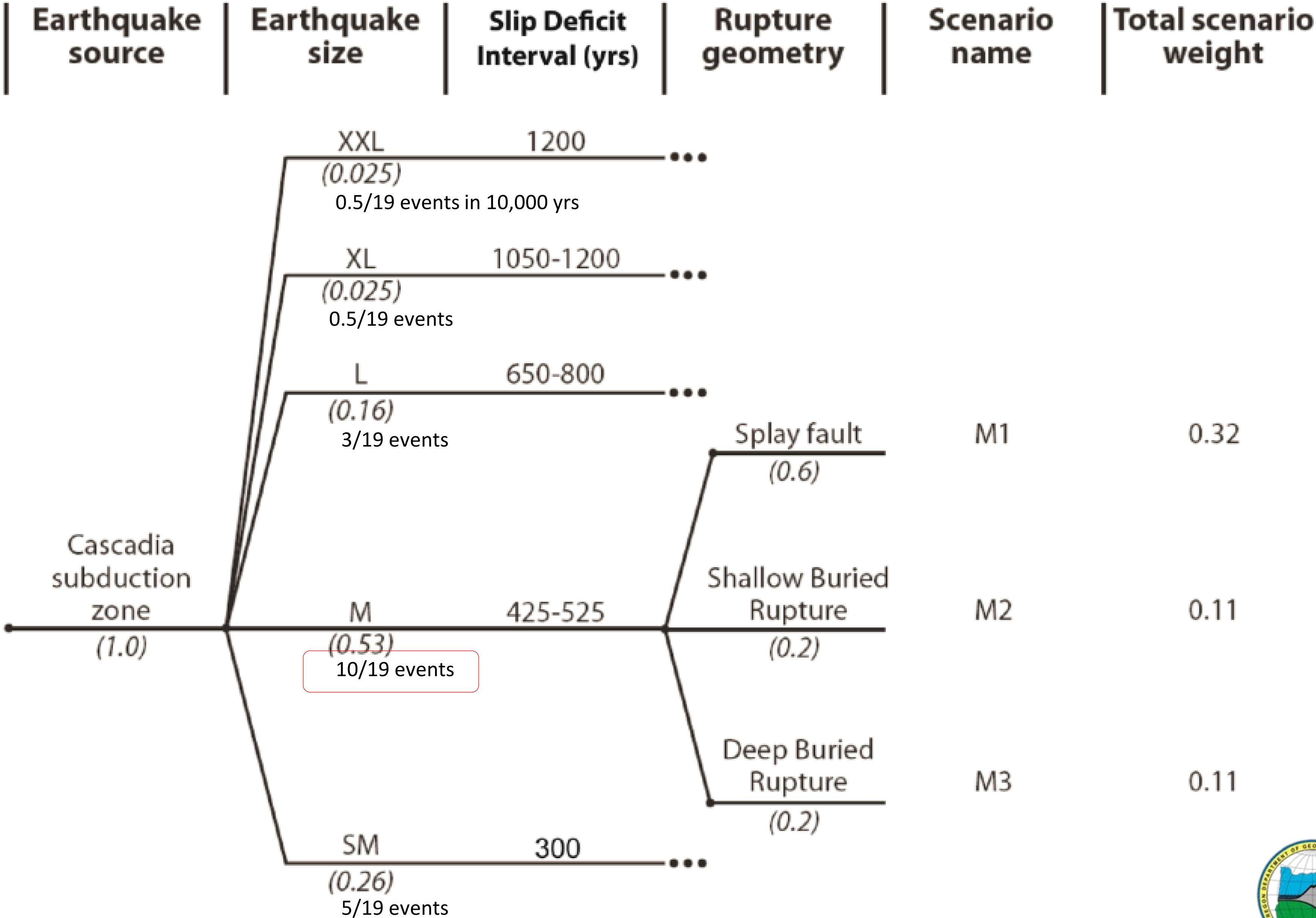
  ~9/18 turbidite follow times over 10,000 yrs

- AD 1700 turbidite = "medium"
  10/19 turbidites = "medium" over 10,000 yrs
  (based on mass of turbidites)



Graph from Witter et al. (2011)

LOGIC TREE FOR 15 FULL-MARGIN CASCADIA SOURCES



Modified from Priest et al. (2013)

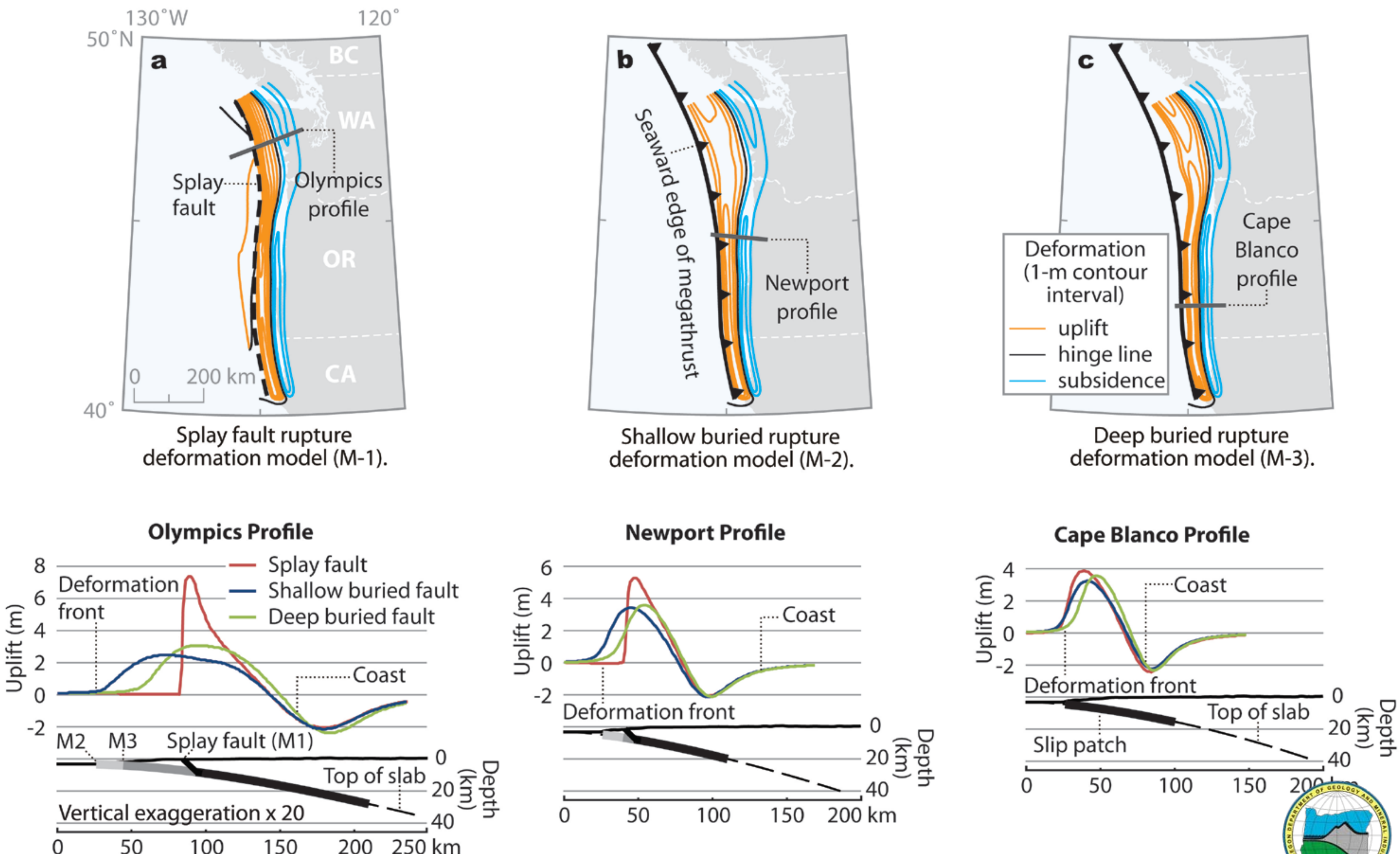
Cascadia Earthquake Source Parameters

(**Red** = Inundation Mapped Statewide; GIS files in **Open-File Report O-13-19**)

Earthquake Size	Slip Deficit (yrs) [Max Slip (m)]	Fault Geometry	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

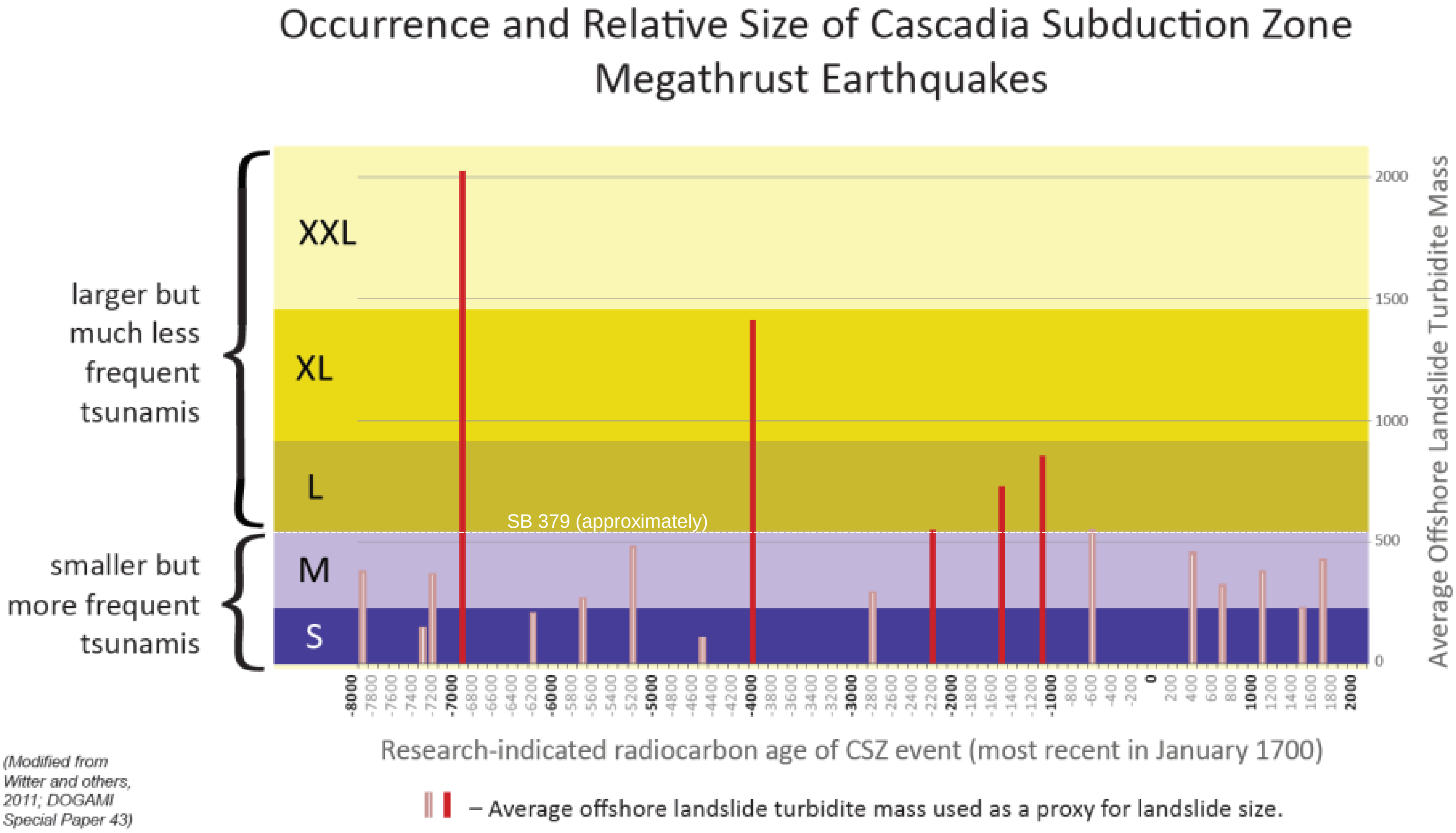
From Witter et al. (2011) with modification by Priest et al. (2013)

“**Medium**” Cascadia Earthquake Deformation Models

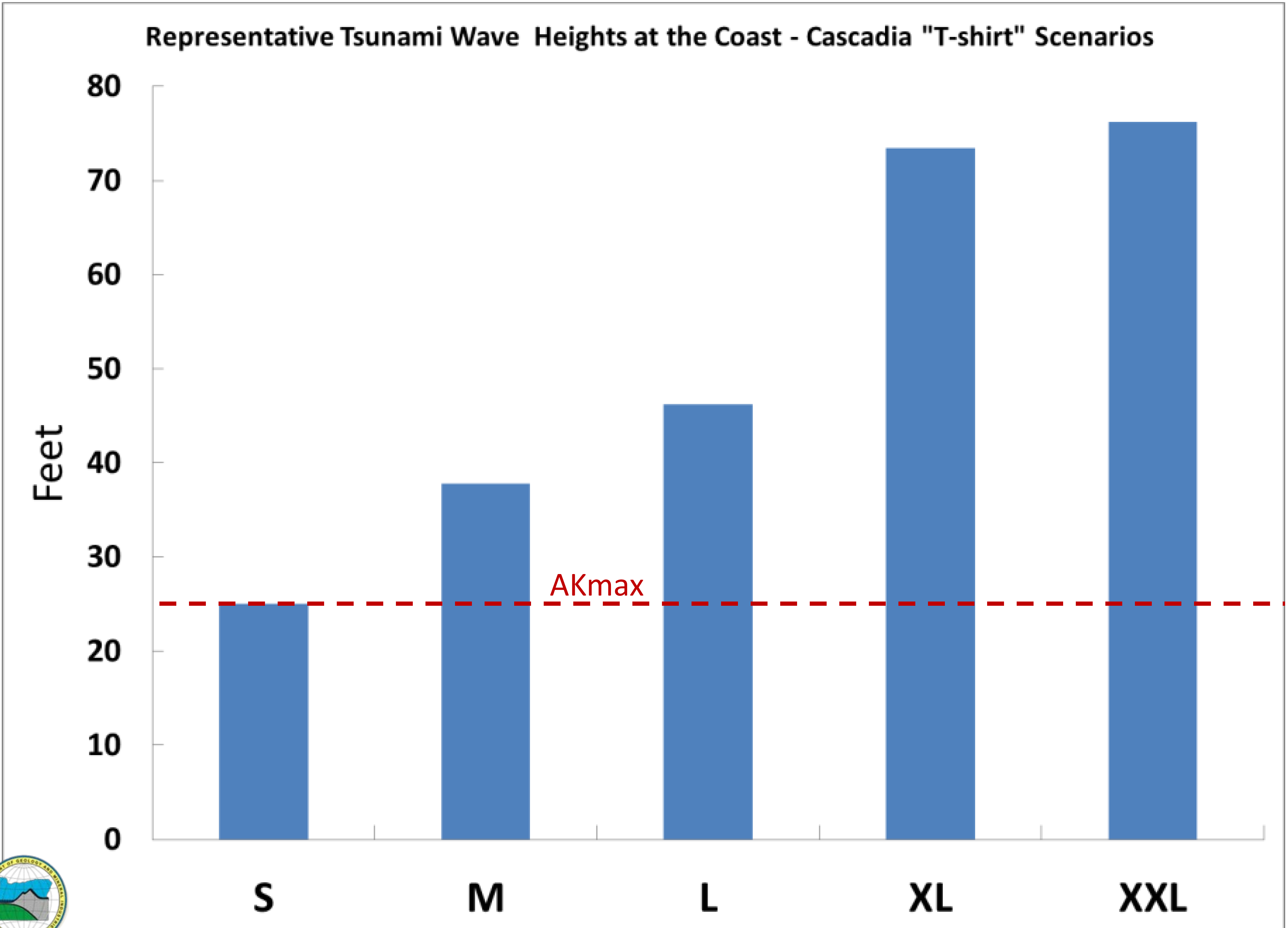


From Witter et al. (2011)

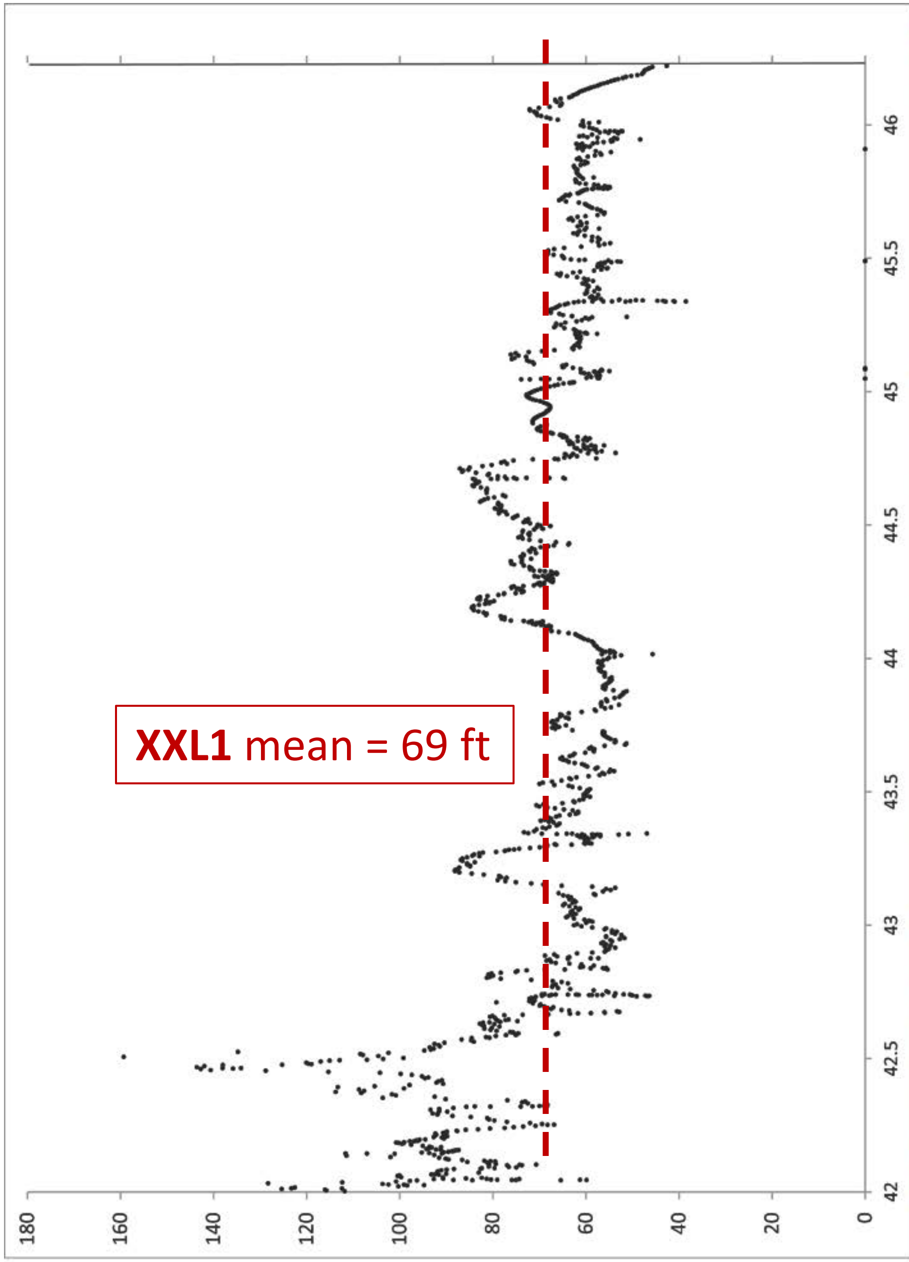
Qualitative Explanation of Cascadia Tsunami Scenarios shown on published tsunami inundation maps (TIMs)



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


Representative Tsunami Wave Heights at the Coast - Cascadia "T-shirt" Scenarios
Feet
80
70
60
50
40
30
20
10
0
AKmax
S
M
L
XL
XXL

Shoreline Tsunami Height is Strongly Affected by Bathymetry



XXL1 Tsunami Elevation (ft NAVD88) at MHHW Shoreline

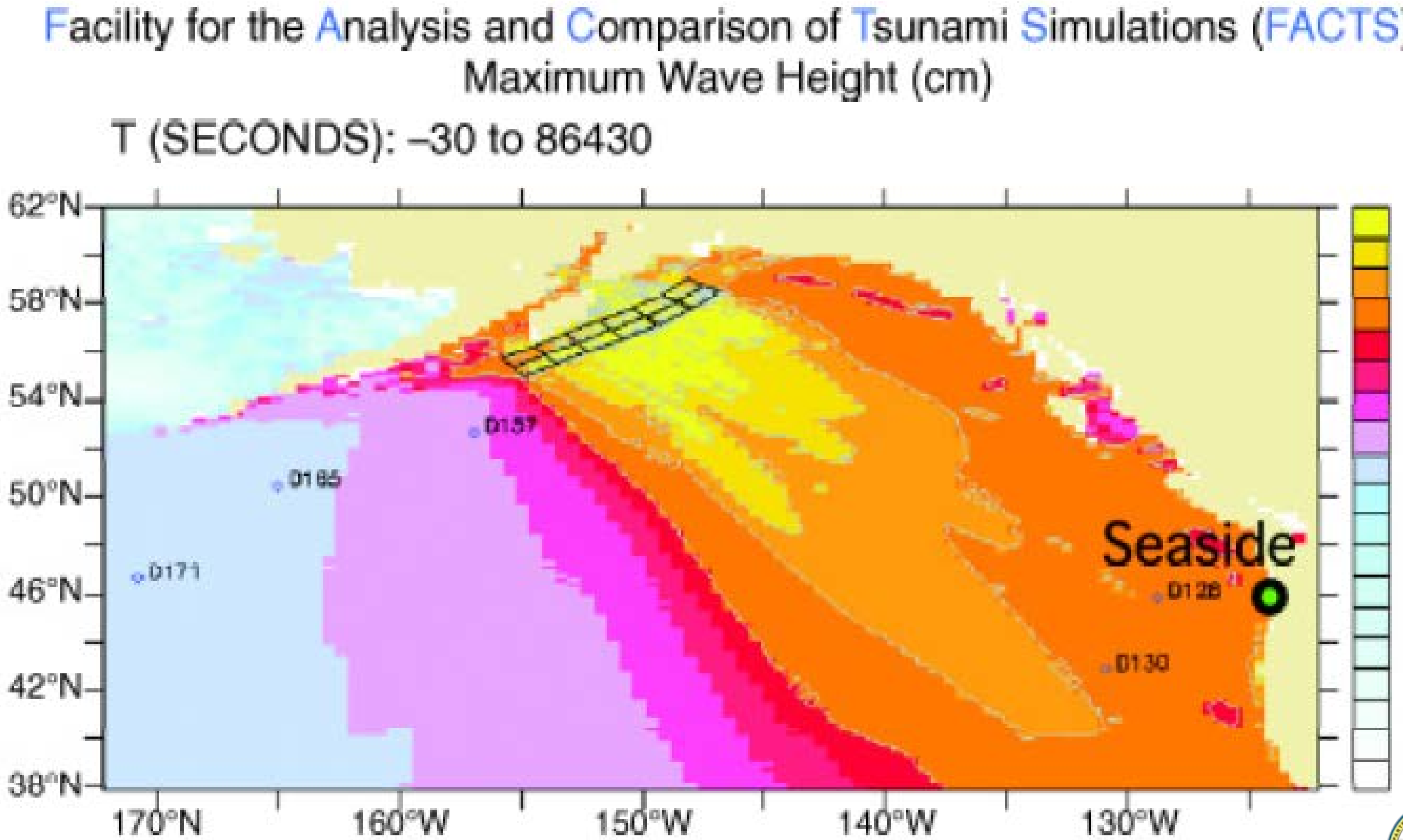
STATEWIDE DISTANT TSUNAMI SCENARIOS

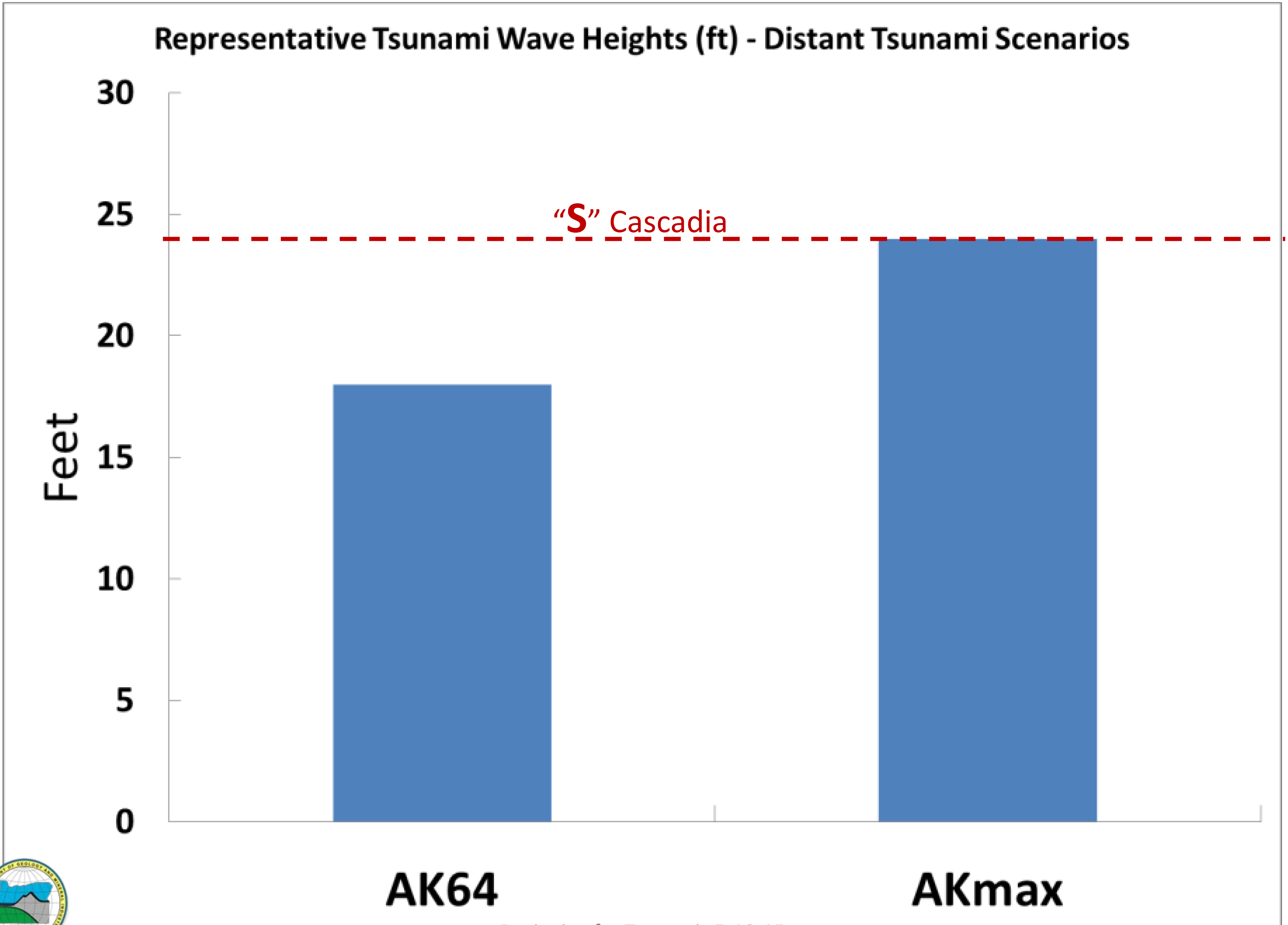
- **AK64**: **Largest historical tsunami**
  (1964 Mw 9.2 earthquake in Gulf of Alaska)
- **AKmax**: **Maximum-considered tsunami**
  (Hypothetical Mw 9.2 earthquake in Gulf of Alaska)

<u>AKmax</u> = Distant Tsunami Evacuation Zone for Oregon

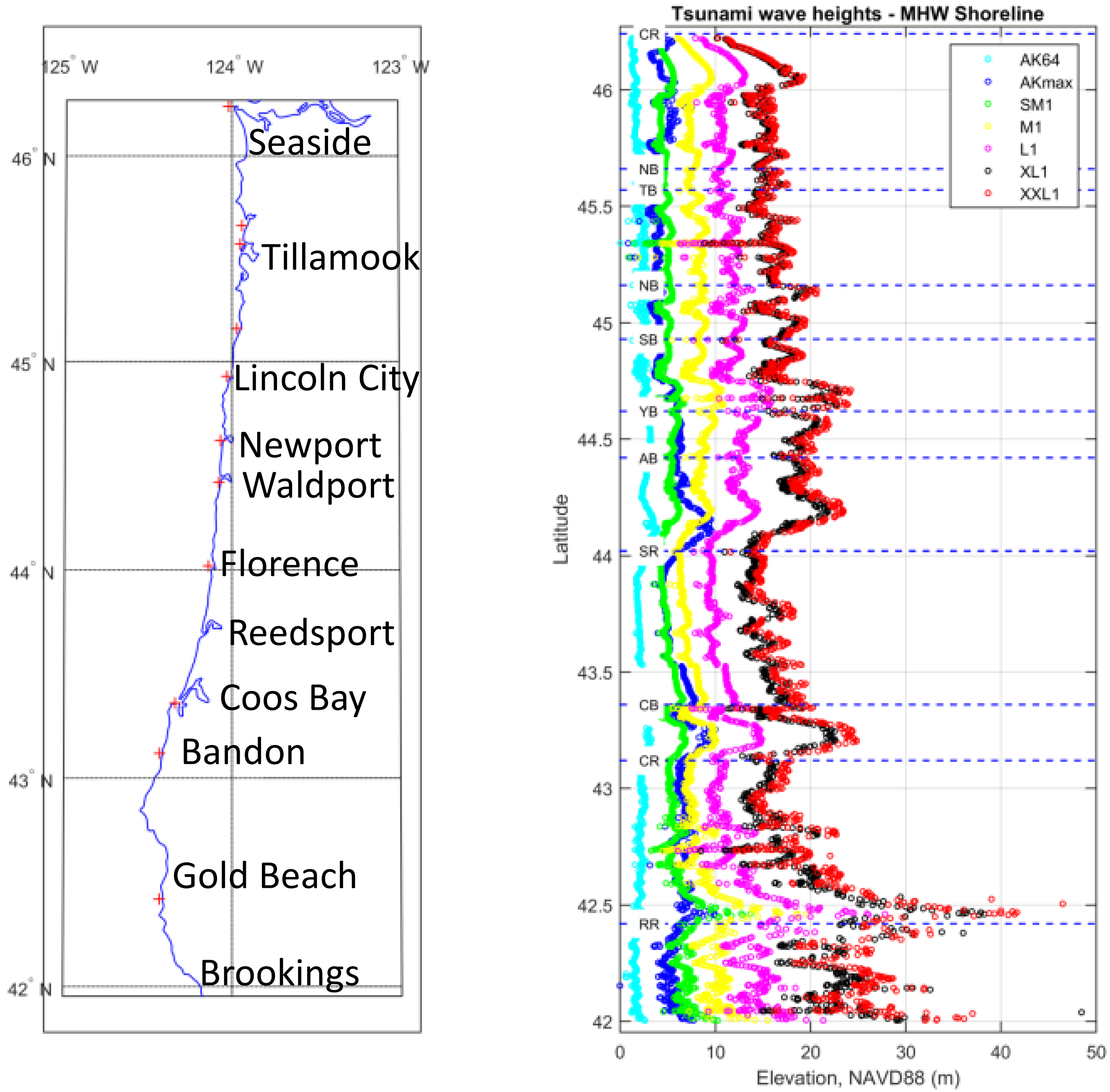
Has maximum directivity to the Oregon coast.

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

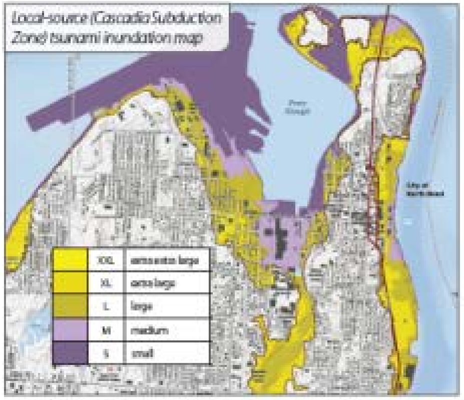




Representative Tsunami Wave Heights (ft) - Distant Tsunami Scenarios
30
25
20
15
10
5
0
Feet
"S" Cascadia
AK64
AKmax


125° W
124° W
123° W
46° N
45° N
44° N
43° N
42° N
Seaside
Tillamook
Lincoln City
Newport
Waldport
Florence
Reedsport
Coos Bay
Bandon
Gold Beach
Brookings
Tsunami wave heights - MHW Shoreline
AK64
AKmax
SM1
M1
L1
XL1
XXL1
CR
NB
TB
NB
SB
YB
AB
SR
CB
CR
RR
Latitude
Elevation, NAVD88 (m)

INUNDATION AND EVACUATION MAP PRODUCTS



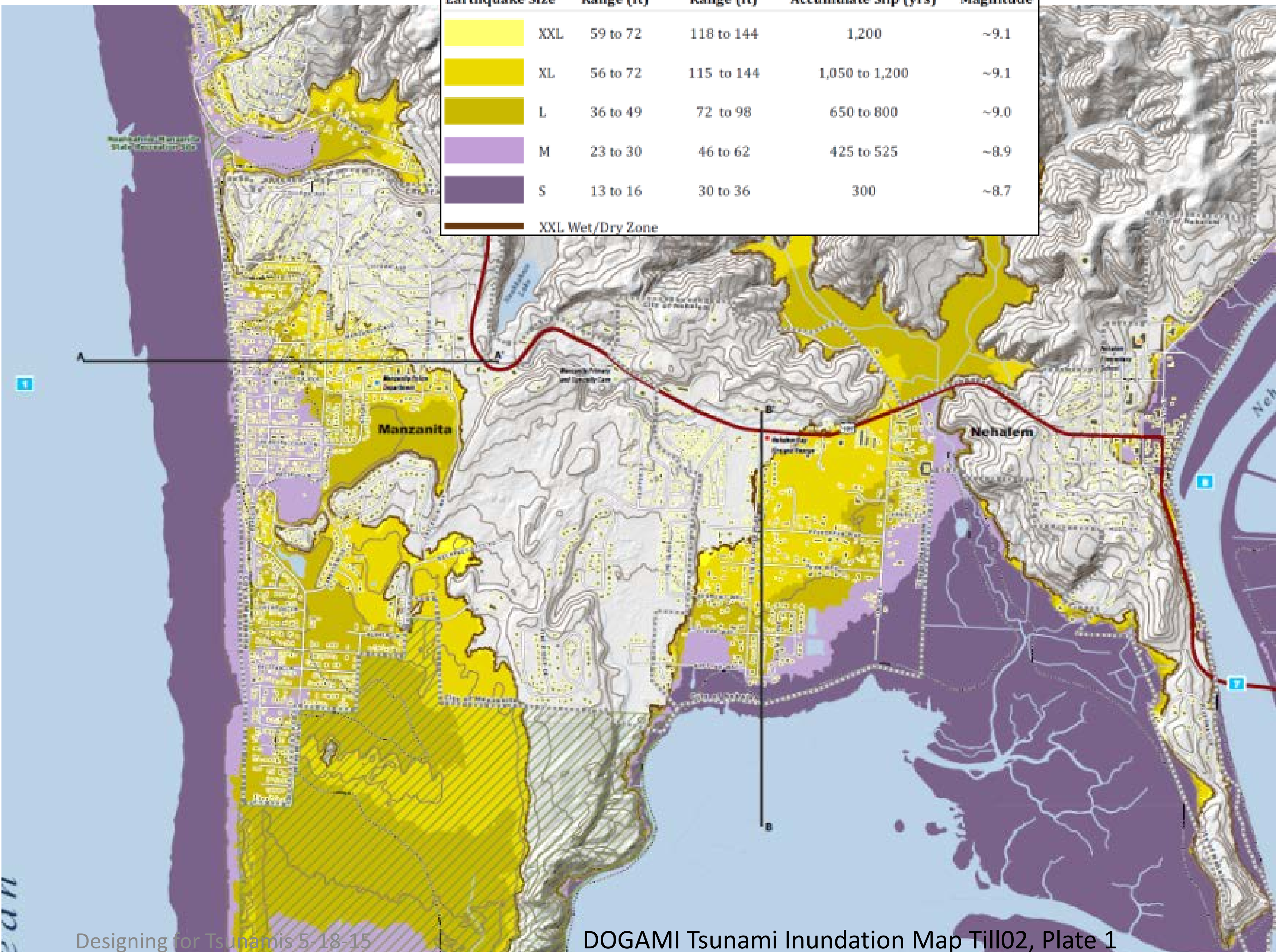
maximum local source (yellow) maximum distant source (orange)

Combine the maximum tsunami scenario from each map ...

- **Inundation Maps (TIMs)** – 7 inundations ***whole coast***
  – **5** **LOCAL** Cascadia "T-Shirt" Scenarios (S, M, L, XL, XXL)
  – **2** **DISTANT** Alaska Scenarios
    - Largest historical (Alaska 1964 – **AK64**)
    - Maximum-considered (**AKmax**)
- **Evacuation Brochures** – **2** inundations ***in towns***
  – **XXL**
  – **AKmax**
  – Routes, preparedness information
- **Evacuation Web Mapper** **2** inundations ***whole coast***
  – **XXL** + **AKmax** on Google type base maps
  – www.oregontsunami.org

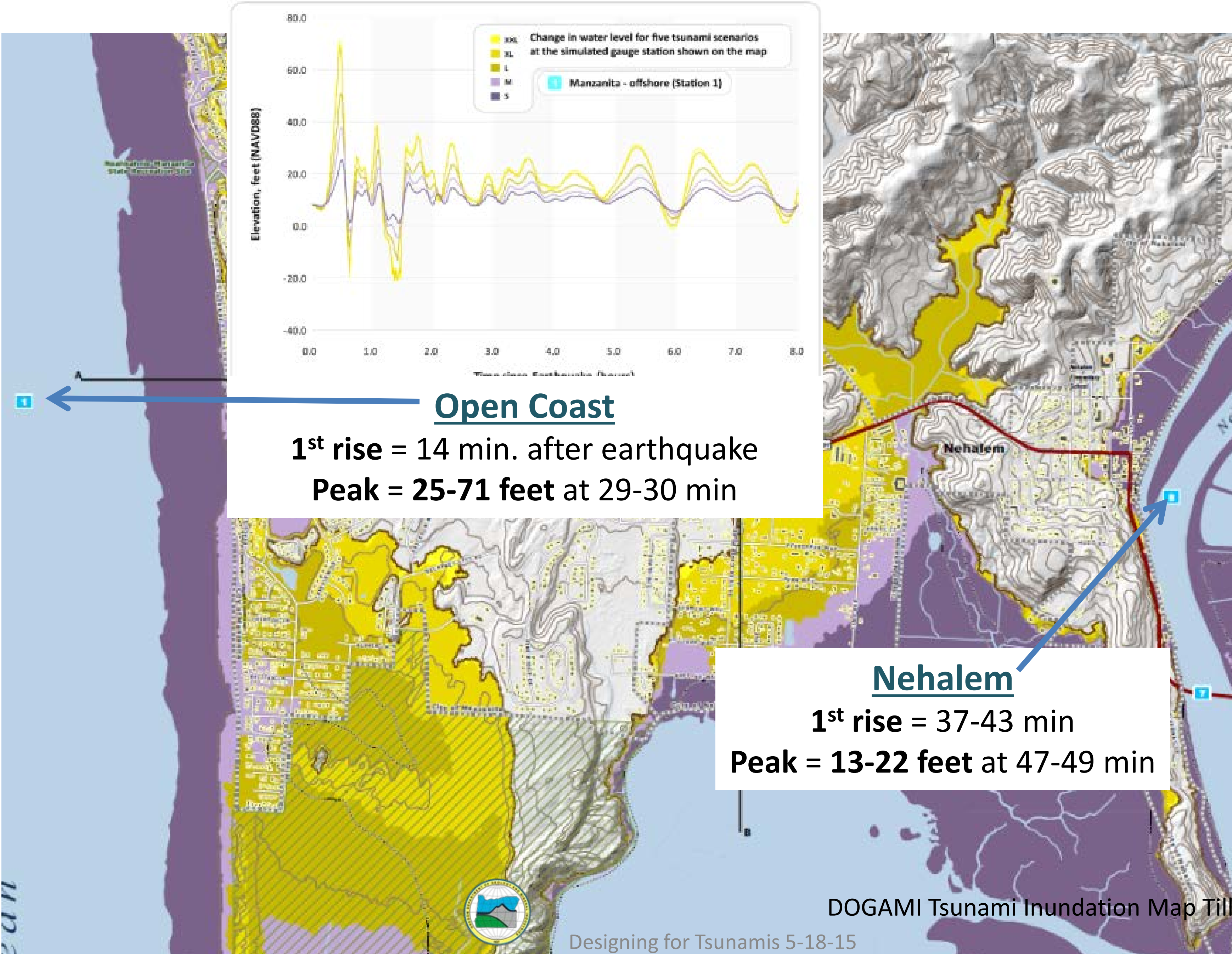
Tsunami Inundation Map (TIM) - Local Cascadia Tsunamis

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				



DOGAMI Tsunami Inundation Map Till02, Plate 1

Tsunami Inundation Map (TIM) - Local Cascadia Tsunamis



Open Coast

1st rise = 14 min. after earthquake

Peak = **25-71 feet** at 29-30 min

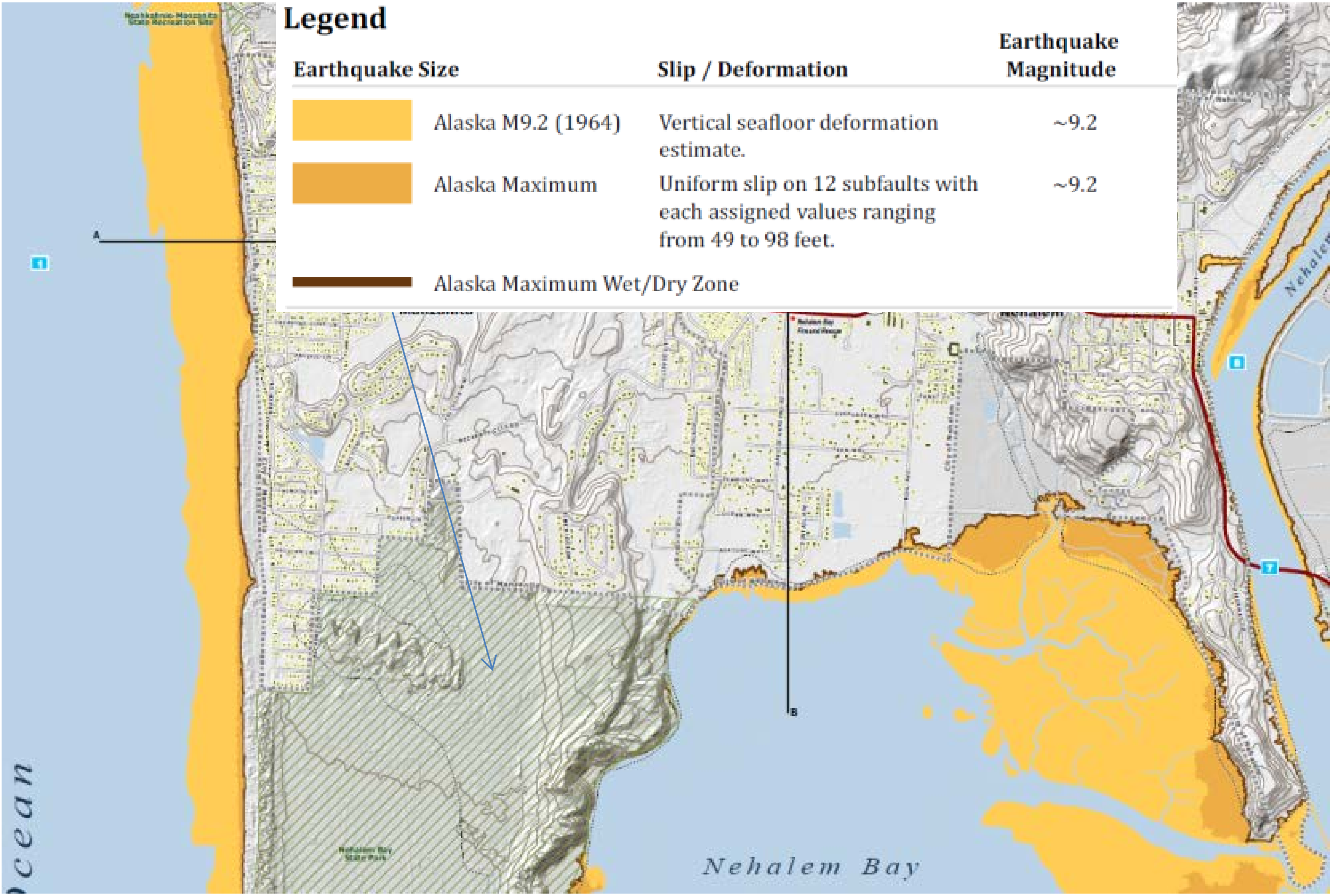
Nehalem

1st rise = 37-43 min

Peak = **13-22 feet** at 47-49 min

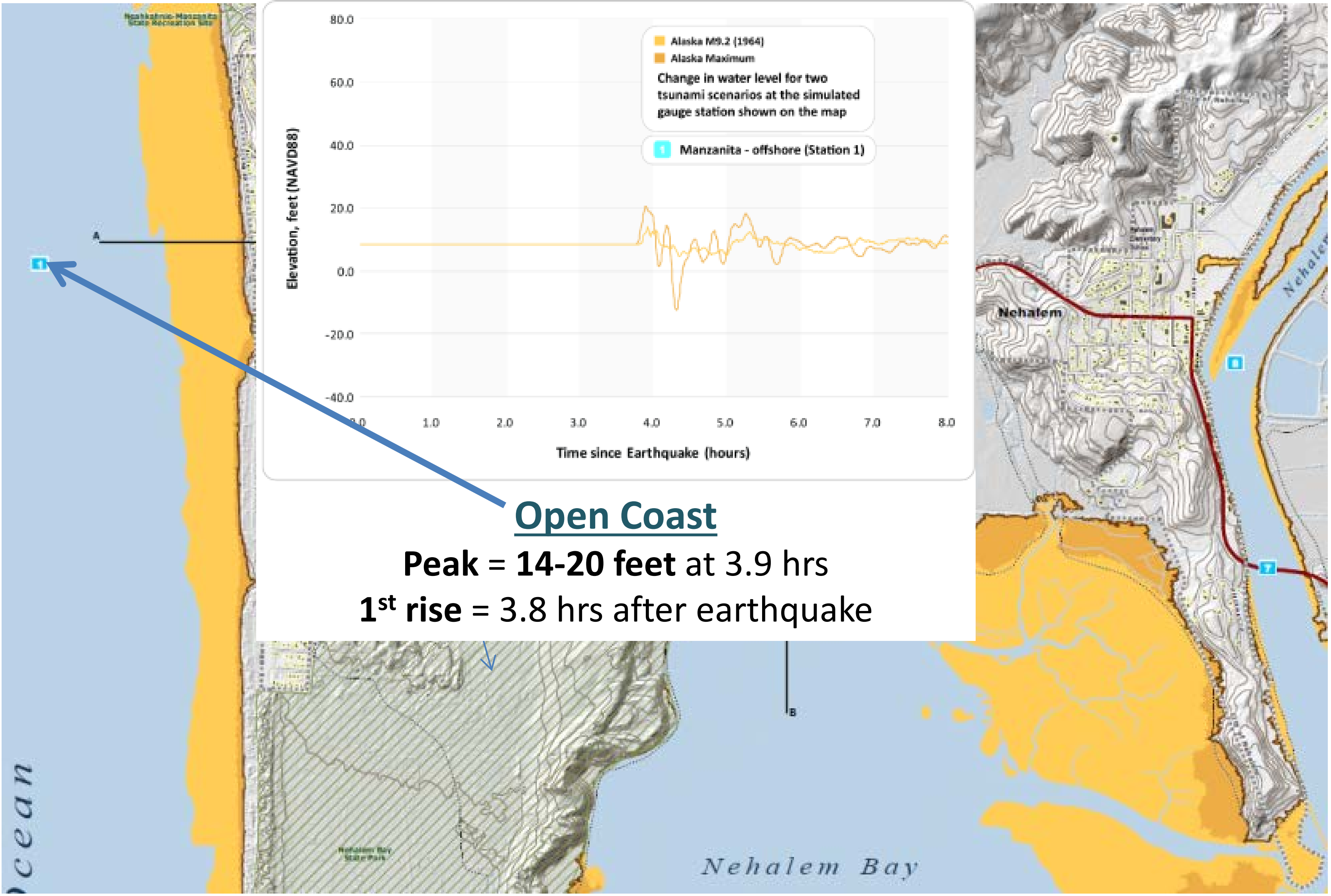
DOGAMI Tsunami Inundation Map Till02, Plate 1

Tsunami Inundation Map (TIM) - Distant Tsunamis



DOGAMI Tsunami Inundation Map Till02, Plate 2

Tsunami Inundation Map (TIM) - Distant Tsunamis



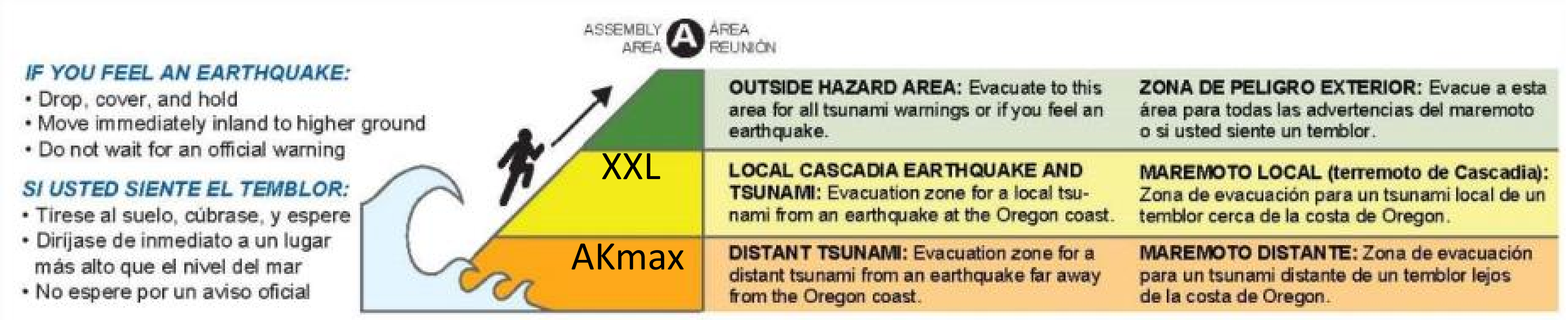
Open Coast

Peak = **14-20 feet** at 3.9 hrs

1st rise = 3.8 hrs after earthquake

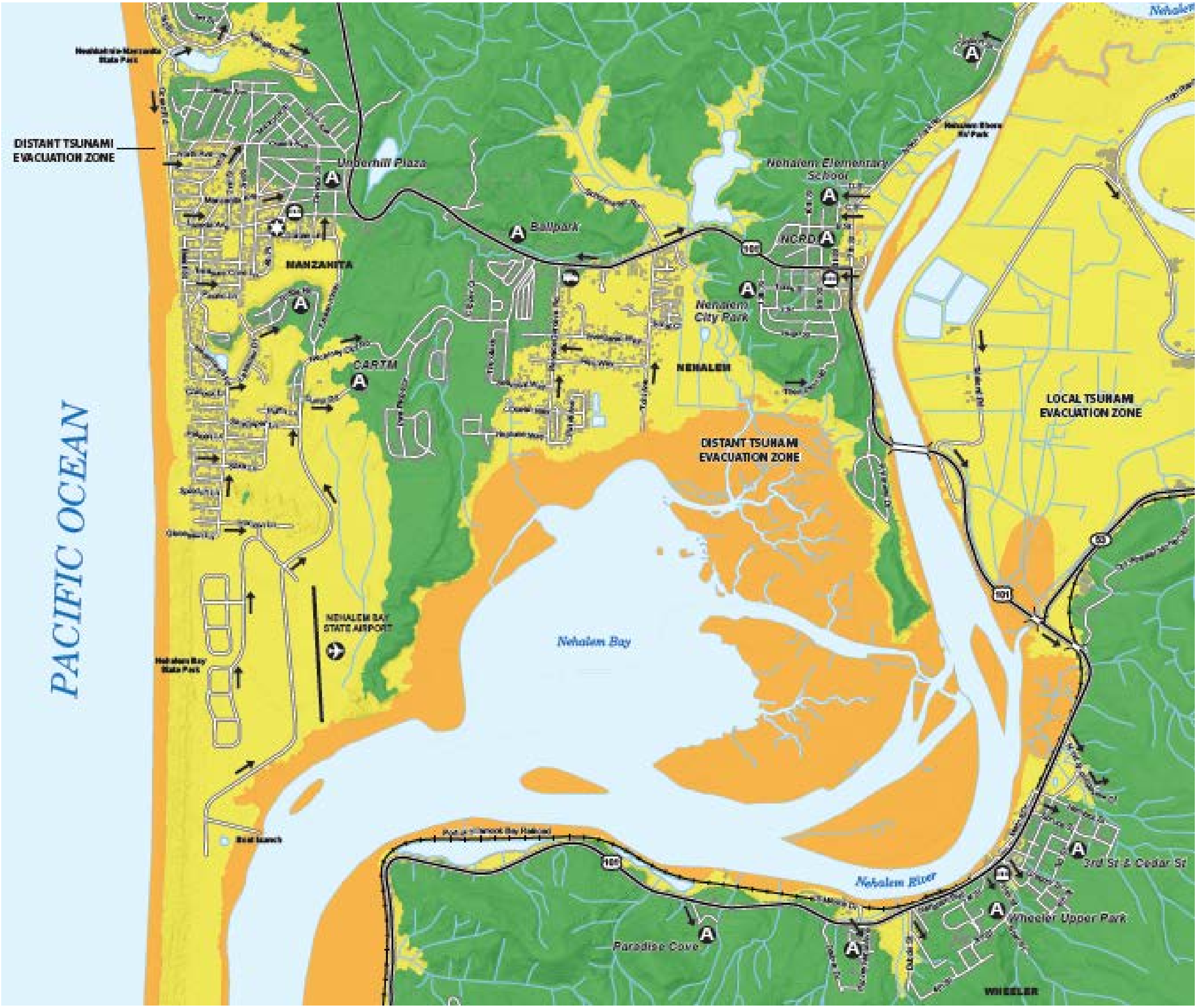
DOGAMI Tsunami Inundation Map Till02, Plate 2

Tsunami Evacuation Map Brochure Explanation

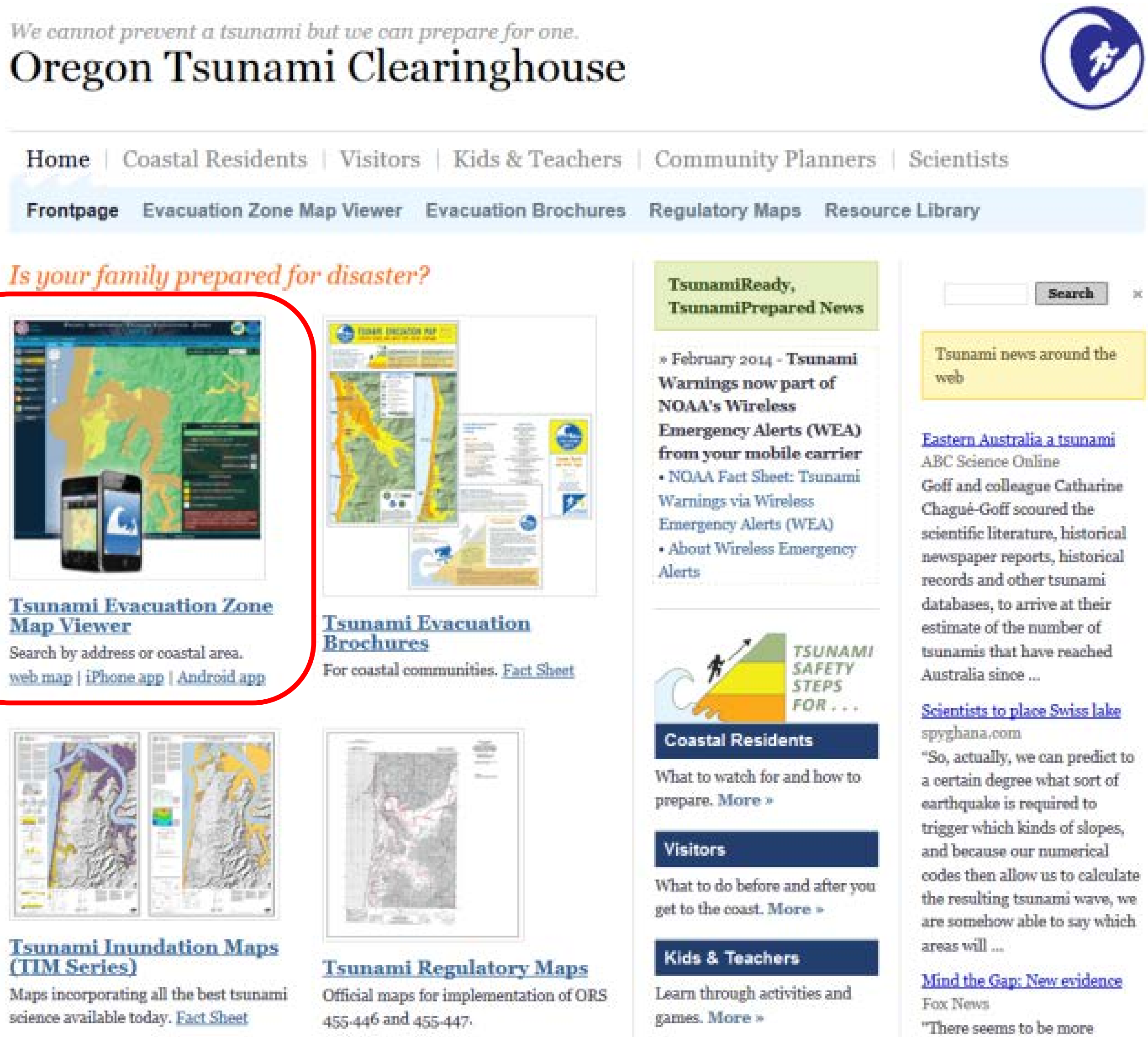


- **GREEN** = outside of both local + distant tsunami inundation
- YELLOW = outside of only distant tsunami inundation

Manzanita-Nehalem Tsunami Evacuation Map



Make your own evacuation map anywhere – just put in an address or zoom in on the viewer! www.oregontsunami.org



Maximum Value Point Data, Time Histories for Selected Points + Animations of XXL1

- ASCII point files of:
  - **Maximum elevation**
  - **Maximum flow depth**
  - **Maximum velocity (north, east, and total vector)**
- **Time histories** in Excel spreadsheets plus PDF graphs
- Order from DOGAMI the DVDs (www.oregontsunami.org):
  - Curry County: Open-File Report **O-13-13**
  - Bandon area: Open-File Report **O-13-14**
  - Coos County: Open-File Report **O-13-15**
  - Douglas, Lane, Lincoln Counties: **O-13-16**
  - Tillamook Co.: Open-File Report **O-13-17**
  - Clatsop County: Open-File Report **O-13-18**

Newly Released Digital Point Data

- ASCII point files of:
  - **Maximum momentum flux**
  - **Minimum flow depth**
  - **Maximum vorticity**
- Order from DOGAMI the DVDs (www.oregontsunami.org):
  - Curry County: Open-File Report **O-14-03**
  - Bandon area: Open-File Report **O-14-04**
  - Coos County: Open-File Report **O-14-05**
  - Douglas, Lane, Lincoln Counties: **O-14-06**
  - Tillamook Co.: Open-File Report **O-14-07**
  - Clatsop County: Open-File Report **O-14-08**

Oregon Revised Statutes (ORS) 455.446 and 455.447: Restrictions on New Development in Oregon’s Tsunami Inundation Zone

SUMMARY

- Restricts new construction of:
  Critical, essential, hazardous, and high occupancy facilities.
- Prohibits (with exemptions):
  - Fire and police stations
  - Hospitals
  - Emergency response facilities
  - Schools >50 people
  - Colleges >500 people
  - Jails
- Not land use planning; only in the building code

Summary of the requirements of ORS 455.447 on new construction in the official tsunami inundation zone

(omits excluded development types; see complete table in DOGAMI OFR-03-05)

Section in ORS 455.477(1)	Type	SB 379 ORS 455.477	Local Exemptions	Prohibited with Exceptions	Must Consult with DOGAMI
aA	Hospitals and other medical facilities with surgery and emergency treatment areas	X		X	
aB	Fire and Police stations	X	X	X	
aE	Structures and equipment in emergency-preparedness centers	X			X
aG	Structures and equipment in government communication centers and other facilities required for emergency response	X		X	
b	Hazardous facility means structures, housing supporting or containing sufficient quantities of toxic or explosive substances to be of danger to the safety of the public if released	X			X
c	Major structure means a building over six stories in height with aggregate floor area of 60,000 square feet or more, every building over 10 stories in height and parking structures as determined by Department of Consumer and Business Services	X			X
eA	Covered structures whose primary occupancy is public assembly with a capacity of greater than 300 persons	X			X
eB	Buildings with a capacity greater than 50 individuals for every public, private or parochial school through secondary level or child care centers	X	X	X	
eC	Buildings for colleges or adult education schools with a capacity greater than 500 persons	X		X	
eD	Medical facilities with 50 or more resident, incapacitated patients not included in subparagraphs A to C above	X			X
eE	Jails and detention facilities	X		X	
eF	All structures and occupancies with a capacity greater than 5,000 persons	X			X

Step A: Proponent develops a proposal and approaches local Building Codes official

Develop concept for coastal facility or structure and approach **local Building Codes official** for applicability of tsunami restrictions.

↓

Official determines applicability of restrictions based upon: location and type of structure or change of structure proposed.

↓

Is site inside inundation zone and subject to restrictions as determined by **Building Codes official**? → No → Proceed to **Planning Department** for permit process.

↓ Yes

Is proposal a water dependent or water related structure as determined by **Building Code official**? → Yes → Proceed to **Planning Department** for permit process.

↓ No

Is proposal an addition, alteration, or repair, as determined by **Building Codes official?** → Yes → Proceed to **Planning Department** for permit process.

↓ No

If proposal is not an addition, alteration or repair, then it qualifies as a new structure or replacement structure or conversion of existing facility to a new use.

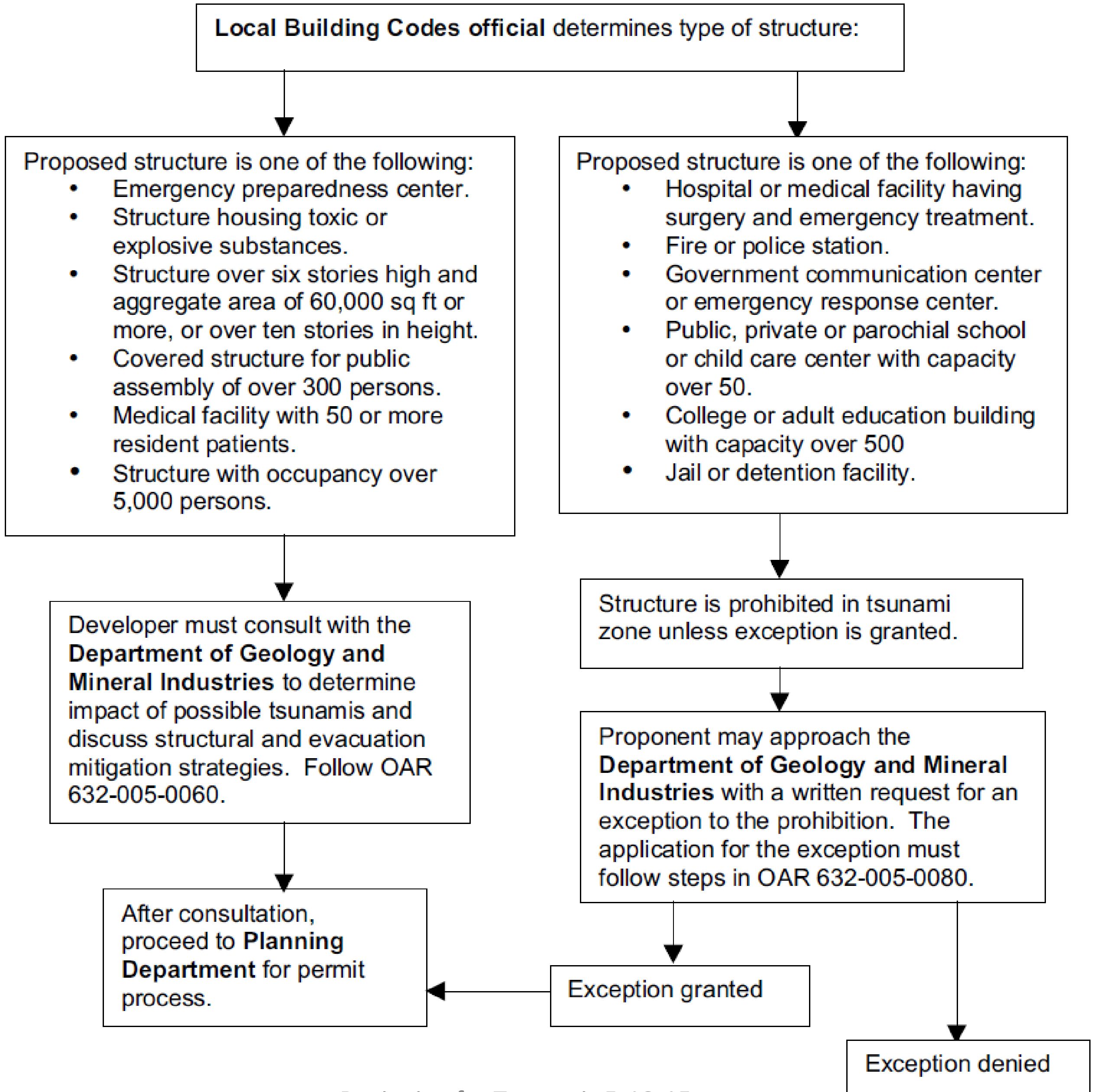
↓

Is structure a fire, police or school deemed by **Building Codes official** to be exempt from restrictions due to need for strategic location? → Yes → Proceed to **Planning Department** for permit process.

↓ No

SB379 restrictions apply. Go to **Step B**.

Step B: Comply with restrictions



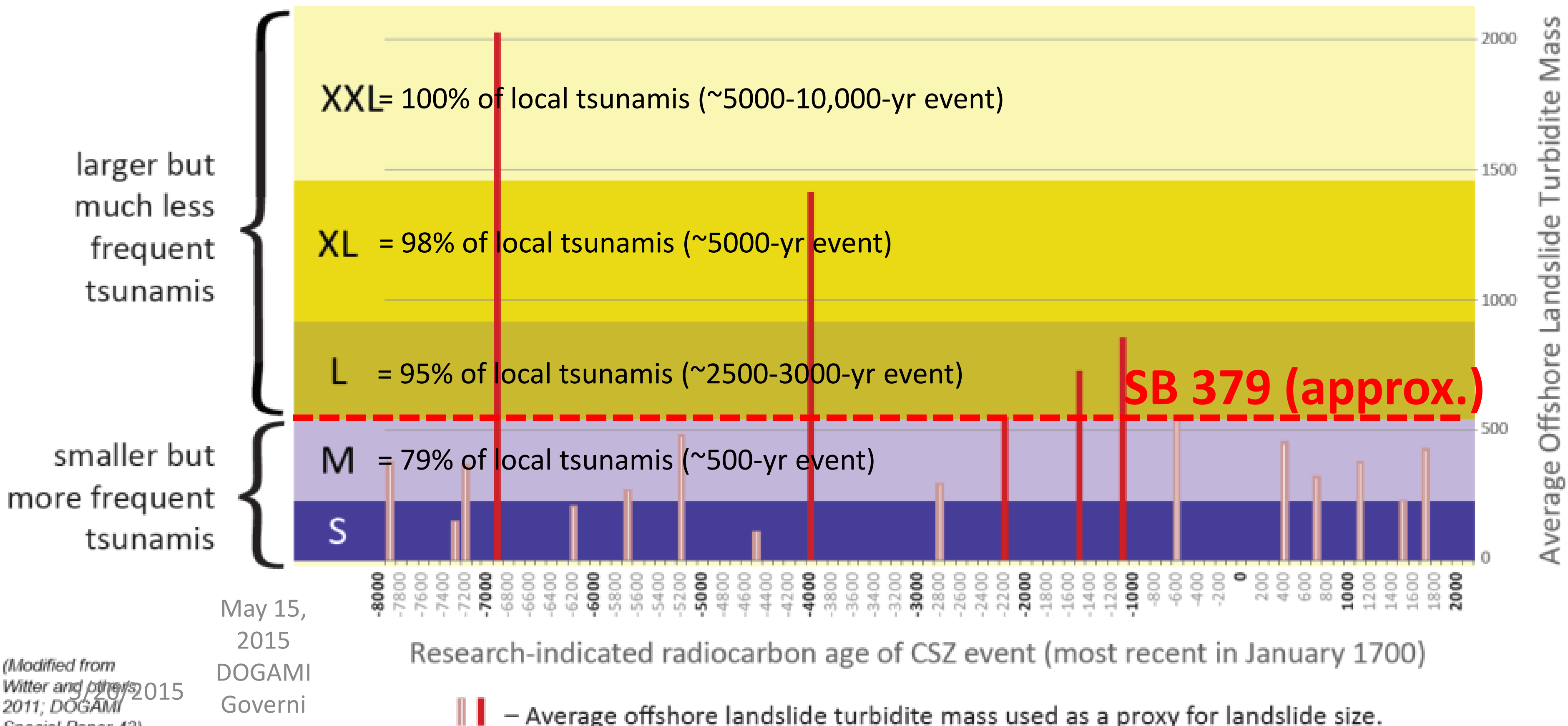
Current SB379 Inundation Zone

- 1995 knowledge base
- "Most likely" Cascadia earthquake = ~M_w 8.8
  - Crude fault source (2 rectangles + uniform slip)
  - Mean fault slip = 37.7 ft
  - Effective offshore uplift = ~7 ft over a broad area
- Inundation estimated from crude computer model.
- Drawn on 52 topographic maps – 20-40'contours
- Line does not always match across map boundaries.
- NOT easily used in GIS ("official line = old paper maps)

Oregon Tsunami Inundation Maps (TIMS)

Five Cascadia Earthquake/Tsunami Size Classes

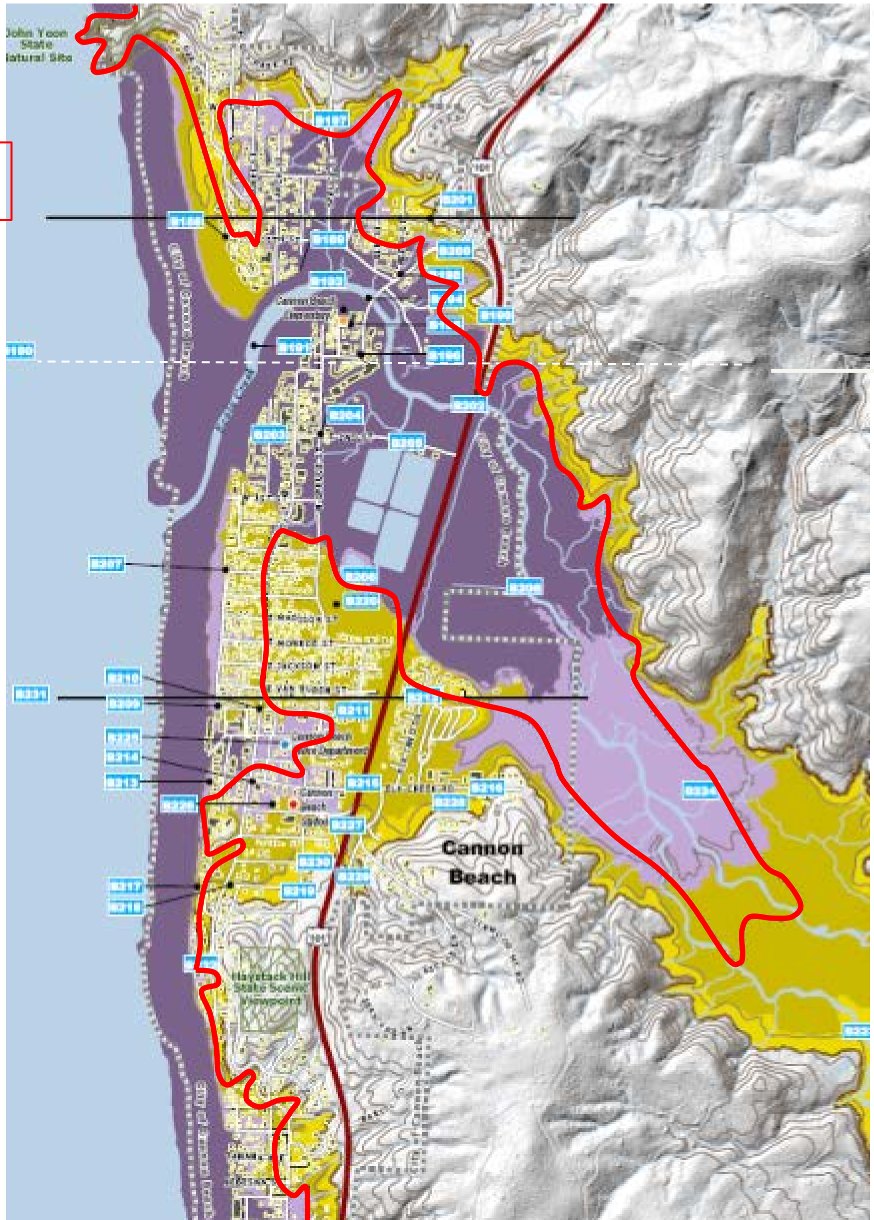
From Size & Frequency of Offshore Turbidites

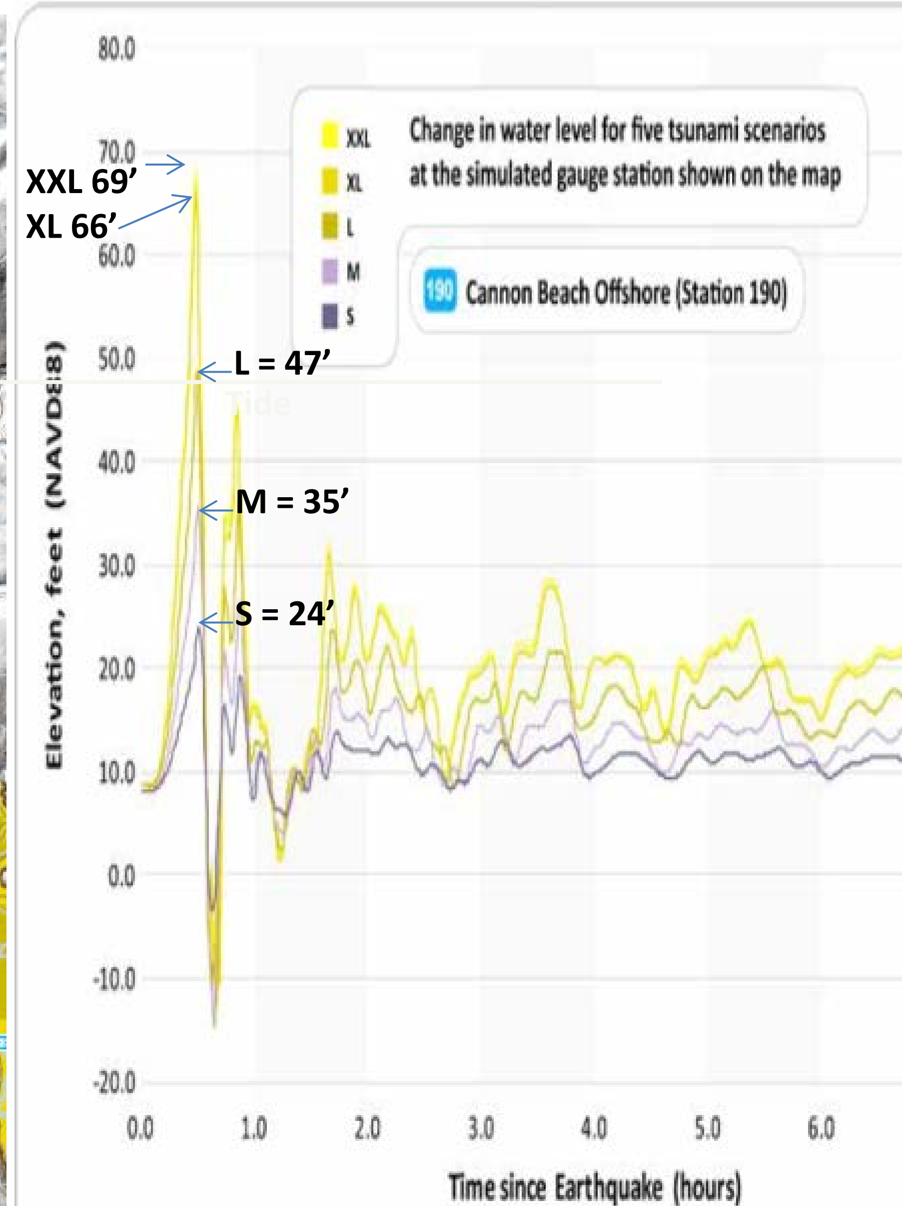


(Modified from Witter and others 2011; DOGAMI Special Paper 43)

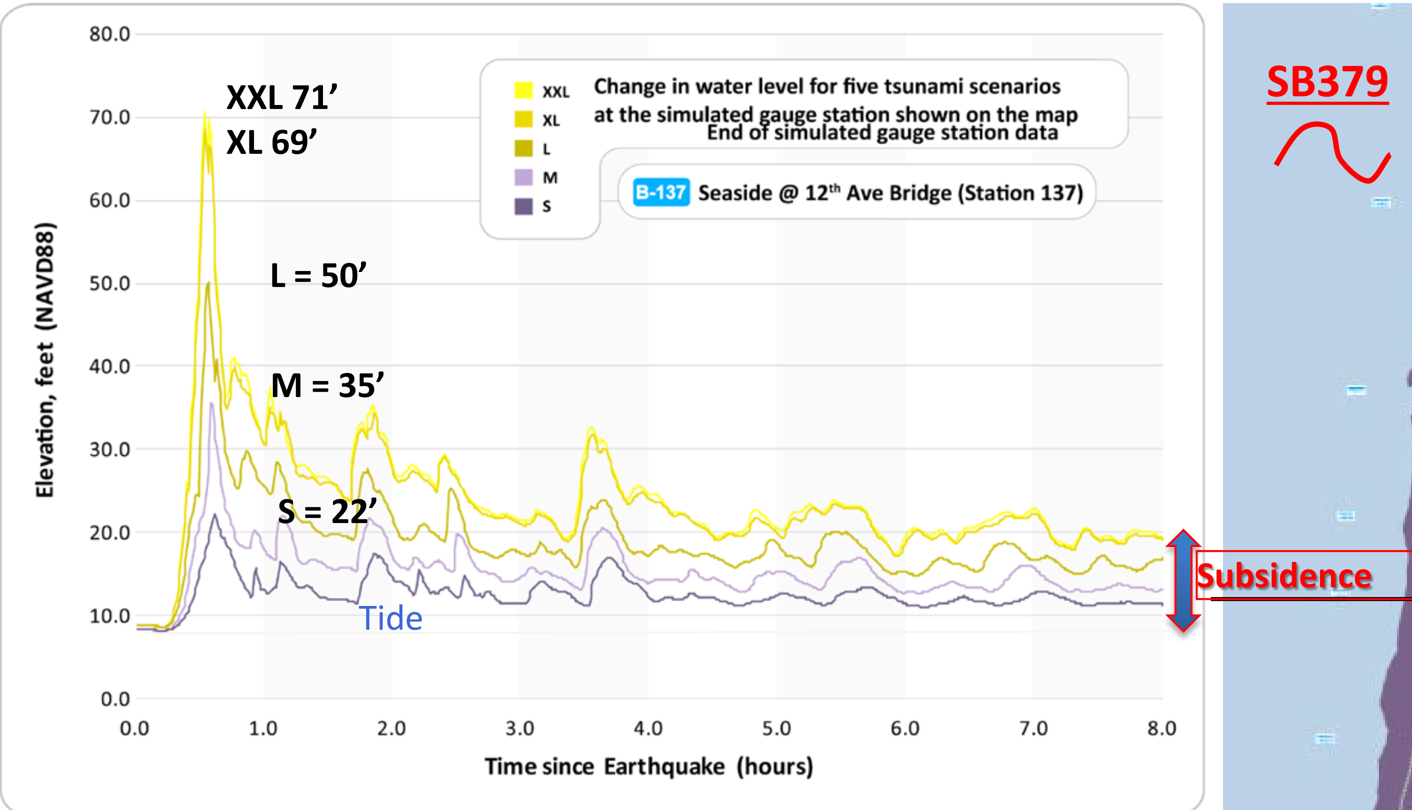
Cannon Beach Local Tsunami TIM

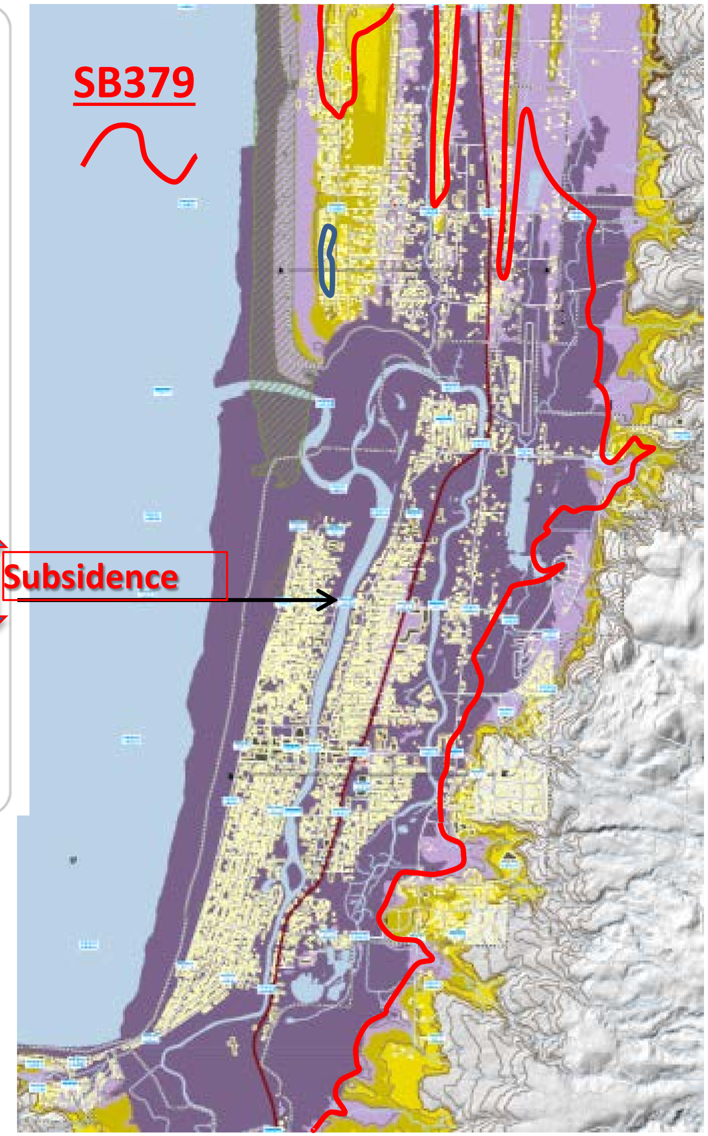
SB379





Gearhart-Seaside Local Tsunami TIM





PROBABILITY OF OREGON CASCADIA TSUNAMI SCENARIOS

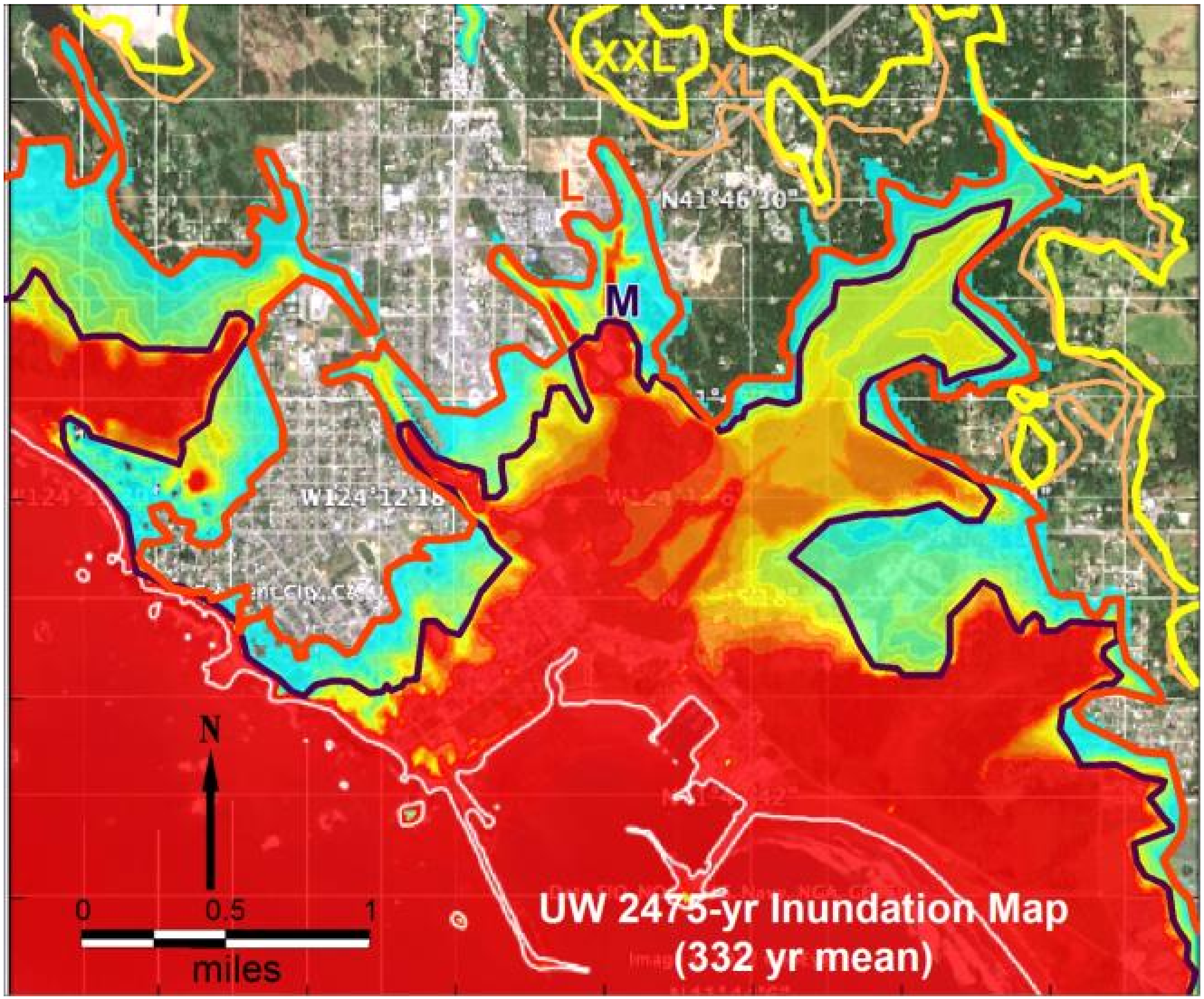
Insights from 2013 Crescent City Pilot PTHA

(Probabilistic Tsunami Hazard Assessment)

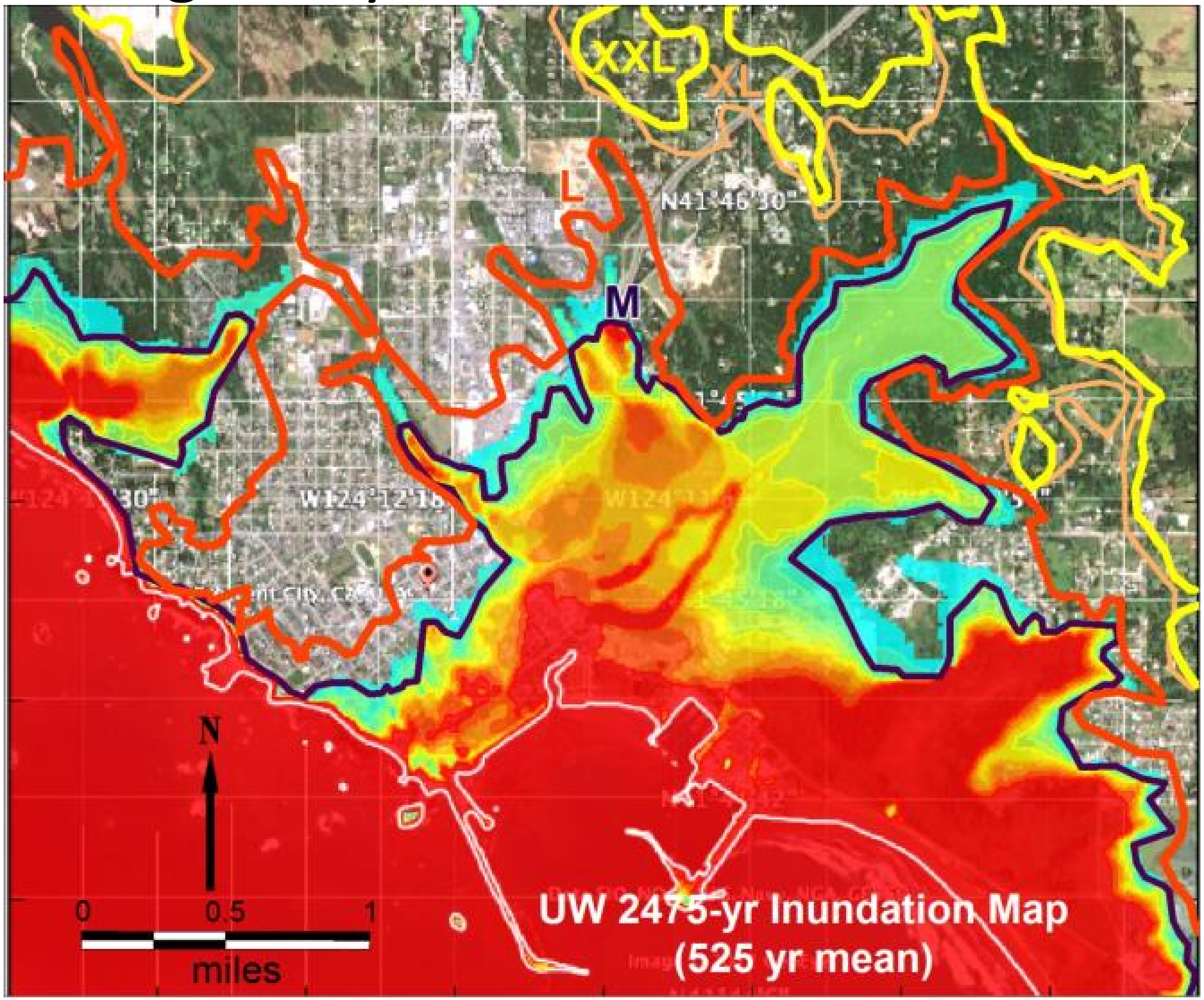
2013 Crescent City Pilot PTHA

- **Sponsors**: California-CGS, FEMA, ASCE, California Coastal Comm.
- **Objectives**
  - **Test approaches to PTHA** at Crescent City
  - **Understand and quantify uncertainties**
  - **500-yr inundation** for land use planning in California (1990 law)
  - **2475-yr exceedance** for critical facilities: for tsunami forces in International Building Code (IBC) (ASCE-7 chapter).
- **Two Competing Teams – 2 Techniques for Cascadia**
  - **URS** (Hong Kie Thio) approach for Cascadia = global analogues, ~500+ scenarios (mainly aimed at IBC 2475-yr exceedance).
  - **UW** (Frank Gonzalez) assume SP43 (Oregon) Cascadia logic tree = 15 realizations of a 500-yr or 332-yr event
  - **BOTH** evaluate similar distant tsunamis + tides, etc.

XXL, XL, L, M vs 2475-yr exceedance
(assuming 332-yr mean return – 2013 **UW PTHA**)

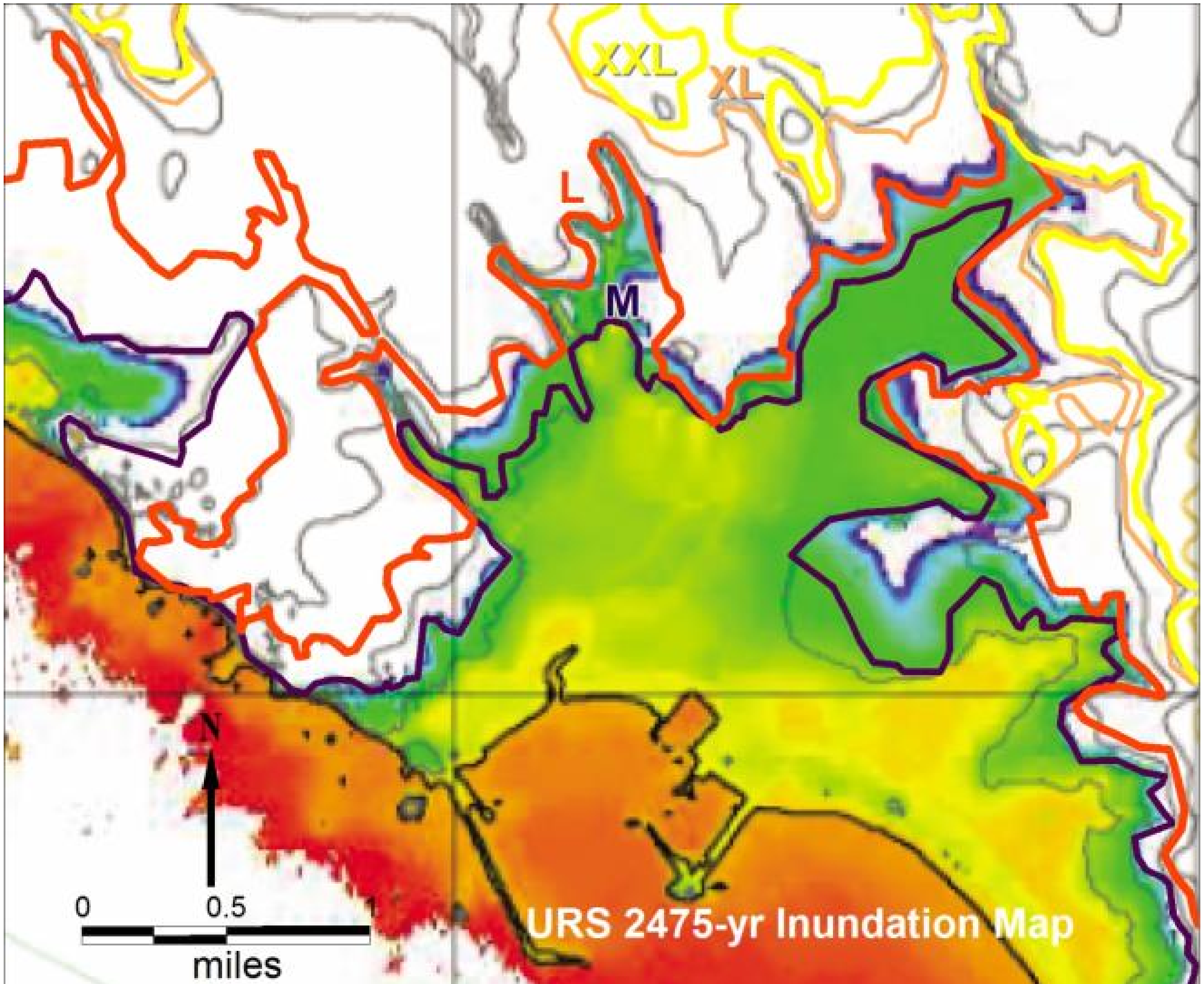


XXL, XL, L, M vs 2475-yr exceedance
(assuming 525-yr mean return – 2013 **UW PTHA**)



Designing for Tsunamis 5-18-15

XXL, XL, L, M vs 2475-yr exceedance
(2013 URS PTHA)



CONCLUSION:
2013 Crescent City Pilot Project

L1 ≈2475-yr exceedance of both UW and URS

NEXT STEPS in evaluation of probability of Oregon Tsunami Scenarios

- Comparison of DOGAMI scenarios to **2014 URS** (Hong Kie) 2475-yr tsunami
  - By Joseph Zhang of Virginia Institute of Marine Studies
  - DOGAMI report in summer 2015
- **2015 UW PTHA** (in collaboration with OSU, Univ. Victoria, George Priest)
  - More robust simulation of CSZ sources based on paleoseismic data, 2015 CSZ convergence rates, and new CSZ geometry
  - Updated fault model
  - Journal publication in late 2015/early 2016