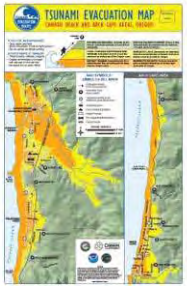
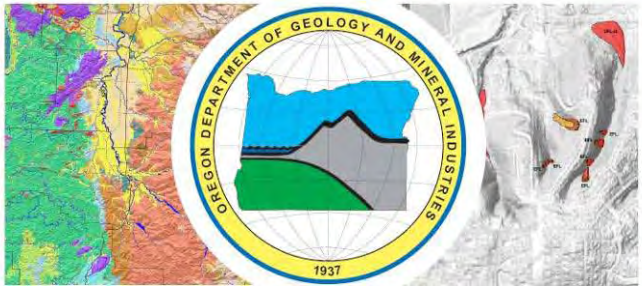





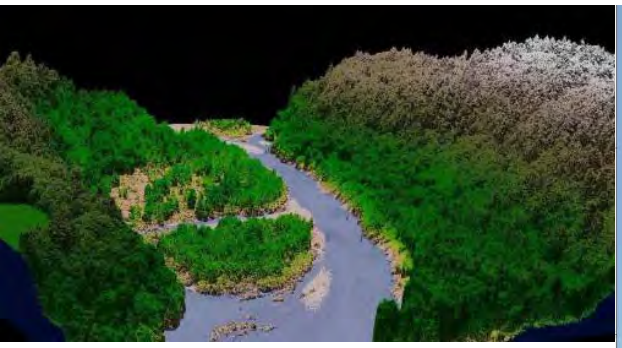
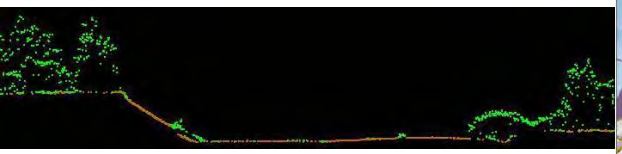
OREGON DEPARTMENT OF GEOLOGY & MINERAL INDUSTRIES

Mission: "Provide Earth Science Information To Make Oregon Safe and Prosperous"

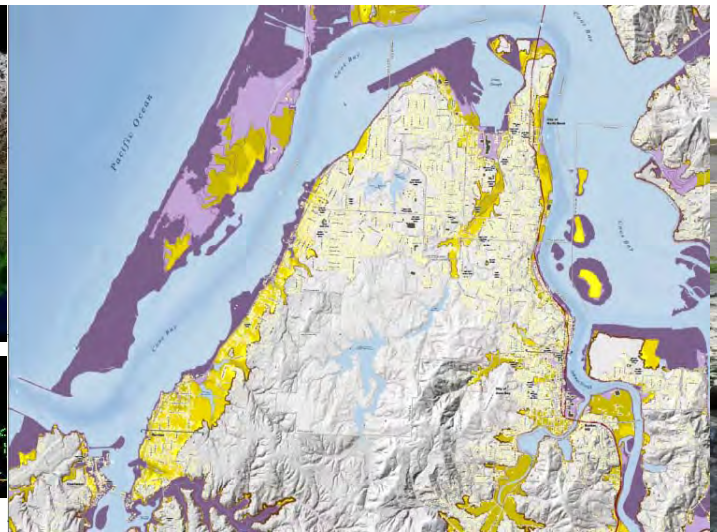
EARTHQUAKES & TSUNAMIS

Manzanita, Nehalem, and Rockaway Beach
April 29, 2012

Lidar

Earthquake/Tsunami Science



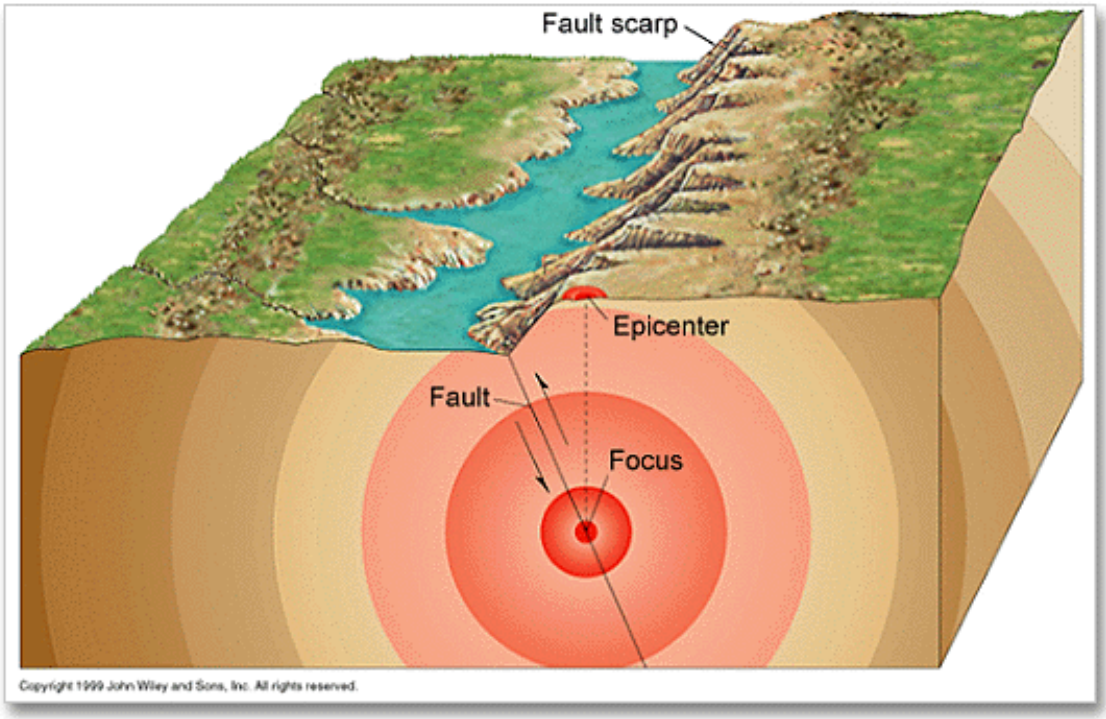
Educate & Mitigate

Today's Presentation

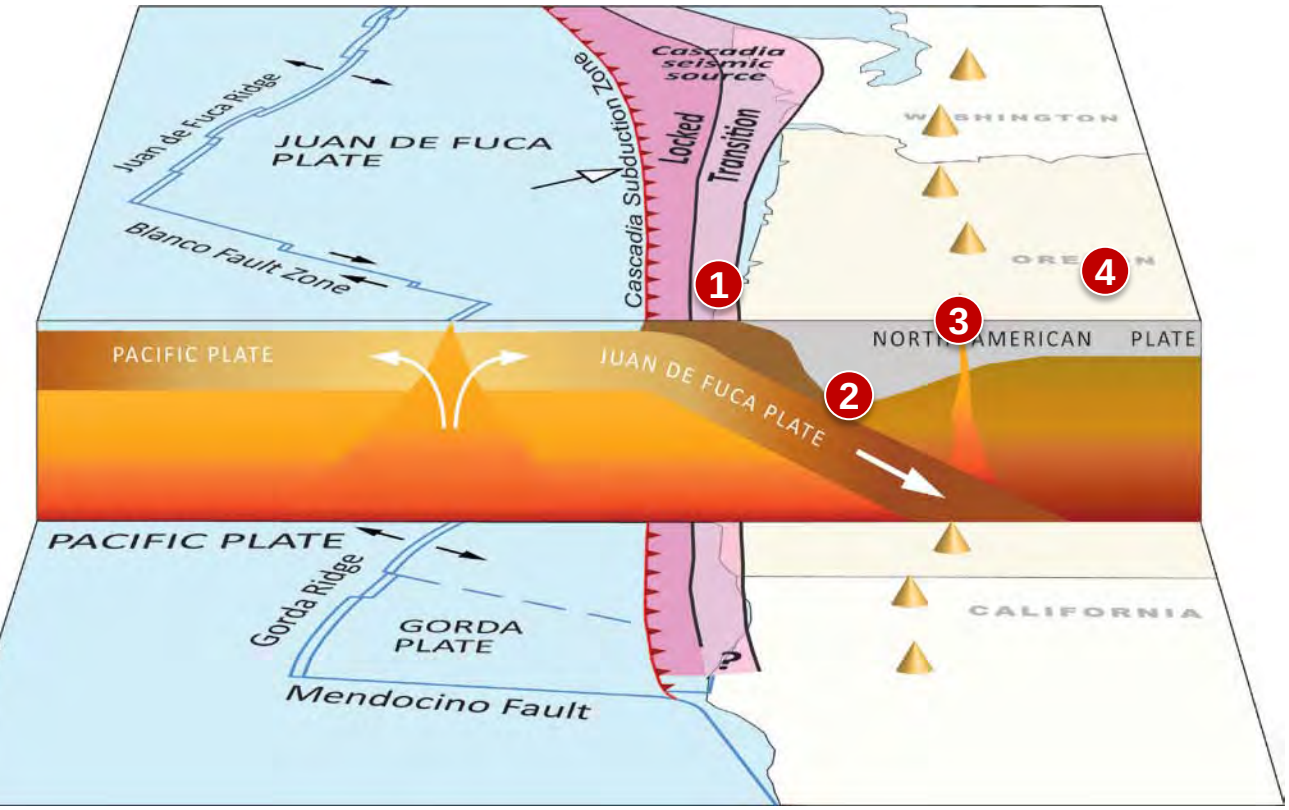
- "Giant" Earthquakes Explained
- Lessons from Japan 2011 Tsunami
- 10,000-year History of Oregon Earthquakes
- New DOGAMI Tsunami Inundation Maps
- New Evacuation Brochures!

Earthquake Basics

- Earthquakes occur along a fault or fault system
- Epicenter = the location on the earth's surface directly above the origin of the earthquake
- Magnitude = a measure of how much energy is released in all directions
- Bigger faults make bigger earthquakes
- Bigger earthquakes last a longer time



Do you know Oregon's four kinds of earthquake sources?



1 Cascadia Subduction Zone

Example: the 1700 earthquake that caused shaking and a tsunami that inundated the OR coast and reached as far as Japan.

2 Interplate

Example: the 2001 Nisqually, WA earthquake that affected Washington and northwestern Oregon.

3 Volcanic

Example: the 1980 Mount St. Helens eruption-related earthquakes.

4 Crustal

Example: the 1993 Scotts Mills and Klamath Falls earthquakes. Crustal earthquakes also occur in SE Oregon where the crust is pulling apart.

Earthquake Frequency & Size

There are many earthquakes each year, only some are felt.

Number of Earthquakes per Year (World)	Number of Earthquakes per Year (USA)	Earthquake Magnitude	Energy Released [Number of Atom Bombs]	Examples
1,300,000	?	2.0	0.00	
130,000	?	3.0	0.00	
13,000	380	4.0	0.00	
1,319	57	**5.0**	0.03	
134	6	**6.0**	0.79	Klamath Falls ('93)
15	1	**7.0**	25	LA ('84) SF ('89) Kobe ('95) Haiti ('10)
1	-	**8.0**	791	China ('76)
-	-	**9.0**	**25,003**	**Sumatra ('04), Japan ('11)**
		9.1	35,005	
		9.3	75,010	Alaska ('64)
		9.5	137,518	Chile ('60)

What Controls the Level of Shaking?

- **Magnitude**: More Energy Released
- **Distance**: Shaking declines with distance
- **Local Soils**: the soil type can amplify the shaking

Loma Prieta, CA 1989

Northridge, CA 1994

Possible Shaking Intensity/Effects

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

III. **Weak** – Felt indoors, especially on upper floors of buildings. Vibrations similar to a passing truck.

IV. **Light** – Vibration felt like passing of heavy trucks. Stopped cars rock. Windows, dishes, doors rattle. Wooden walls and frames creak.

V. **Moderate** – Felt by nearly everyone; sleepers awakened. Small, unstable objects overturned. Doors swing. Pictures move. Pendulum clocks stop.

VI. **Strong** – Felt by all. People walk unsteadily. Some heavy furniture moved. Small objects fall off shelves. Pictures off walls.

VII. **Very strong** – Difficult to stand or walk. Noticed by drivers of cars. Slight to moderate damage in well-built structures; considerable damage in poorly built structures.

VIII. **Severe** – Steering of cars affected. Extensive damage to buildings with partial collapse. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Wood-frame houses moved on foundations if not bolted.

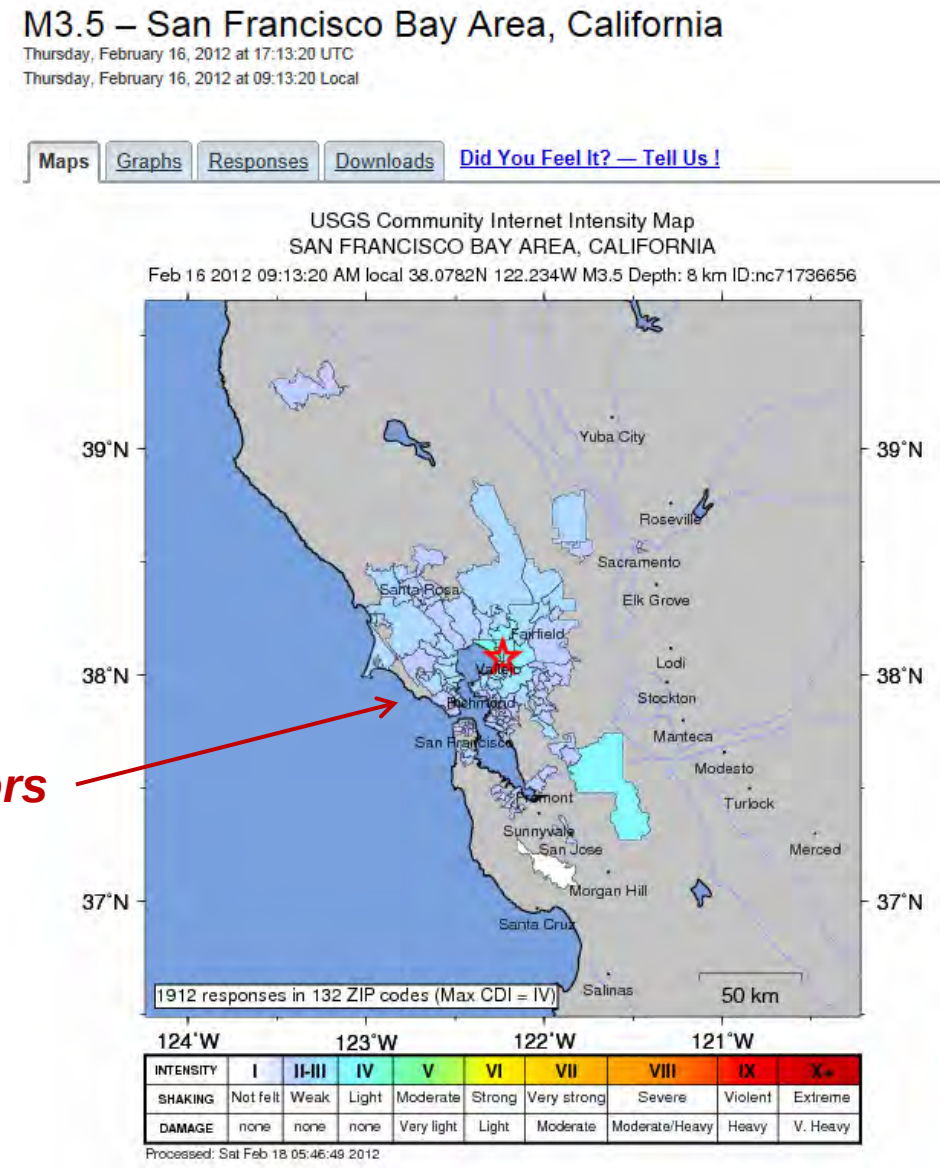
IX. **Violent** – General panic. Damage to buildings ranges from collapse to serious damage.

M3.5 Earthquake *Might* be Felt

February 16, 2012

- **San Francisco Area**
  - **Magnitude 3.5**
  - **5 miles deep**
    - **9:13am local time**
    - **Reported as Felt by 1,912 people**

Note the shaking intensity colors

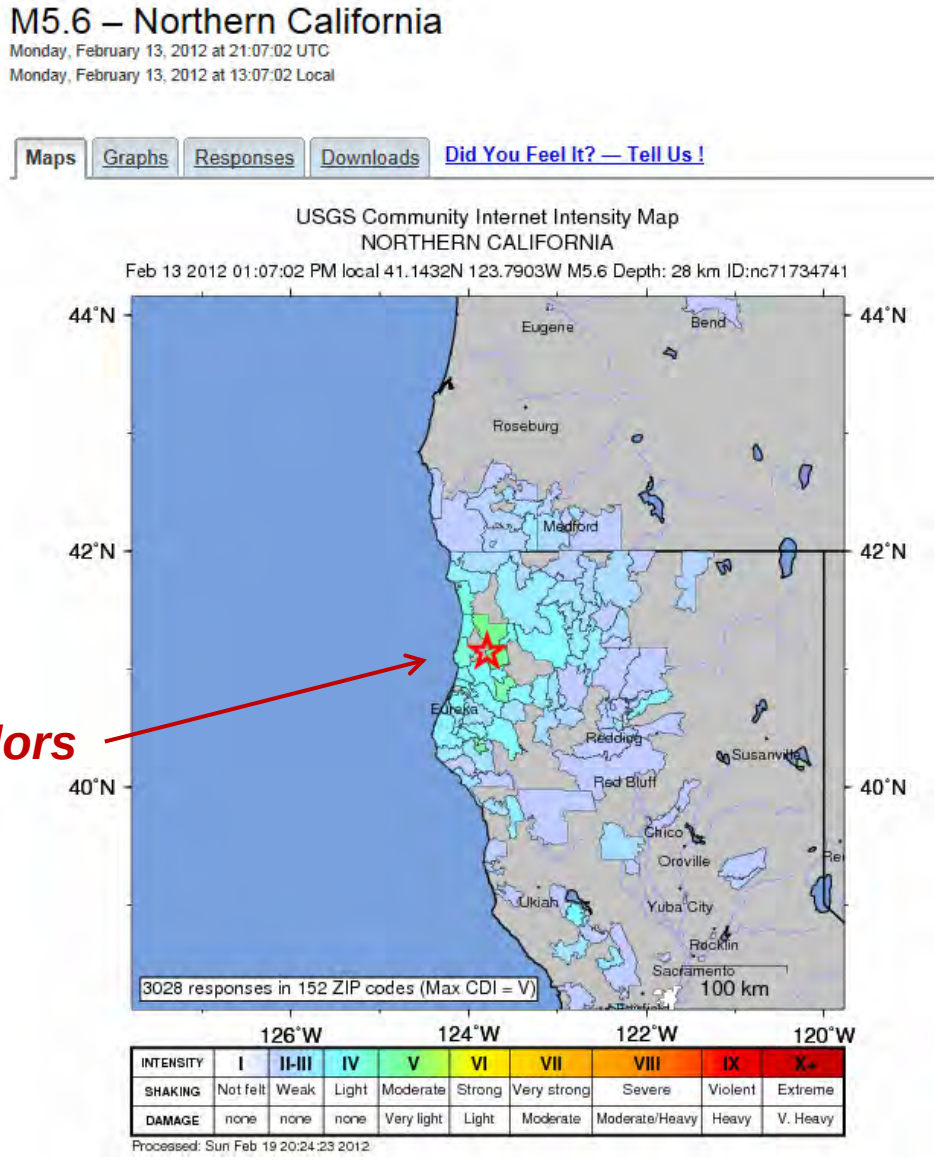


M5+ Earthquake *Usually* Felt

February 13, 2012

- **Northern California**
  - **Magnitude 5.6**
  - **17 miles deep**
    - **1:07pm local time**
    - **Reported as Felt by 3,028 people**

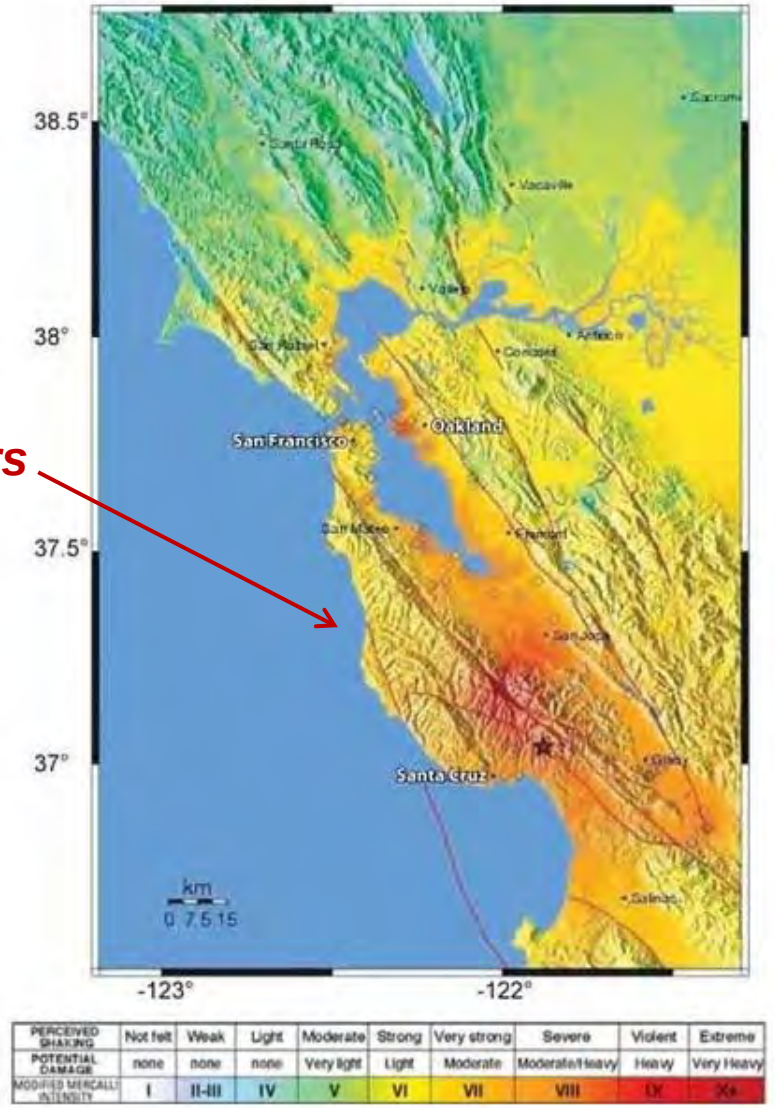
Note the shaking intensity colors



M7 Earthquake

- **Ground Can Shake *Moderately* For 30 Seconds**
- **Poor Soils Can *Amplify* Effects**
- **Damage Can be *Moderate to Heavy* (*even* with current building codes)**

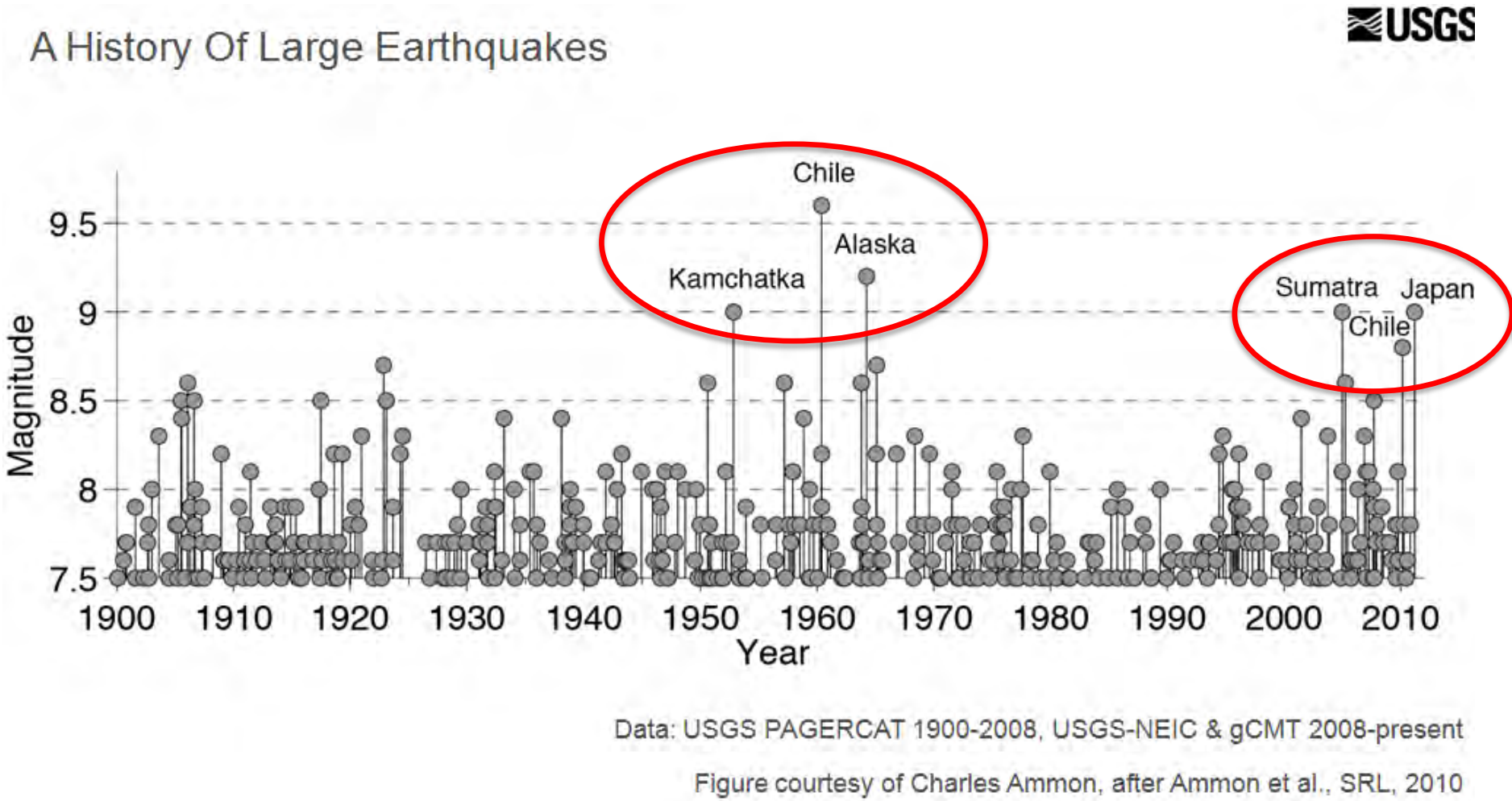
Note the shaking intensity colors



Other Earthquake Effects:

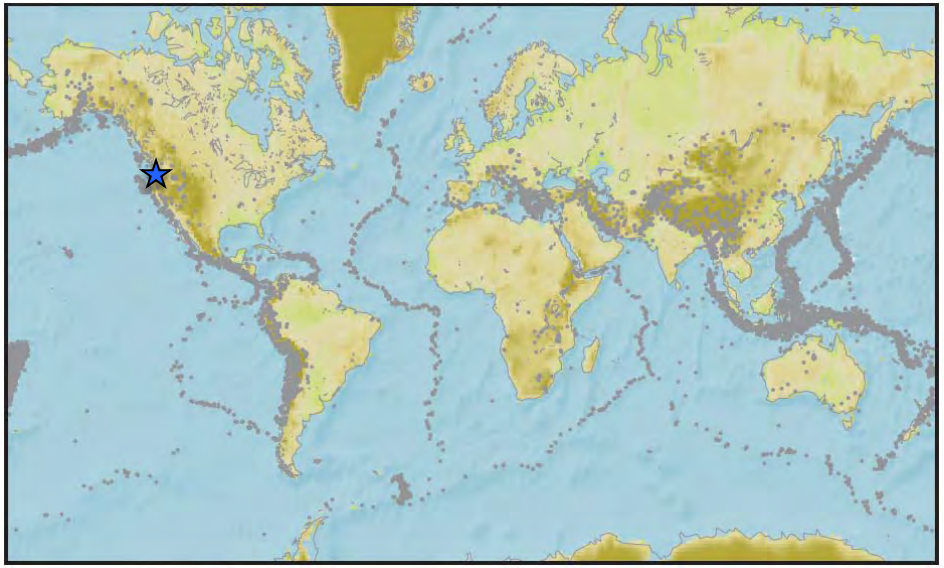
- **Liquefaction**
- **Subsidence/Uplift**
- **Landslides**
- **Fires**
- **Tsunamis**

Large Earthquake Frequency

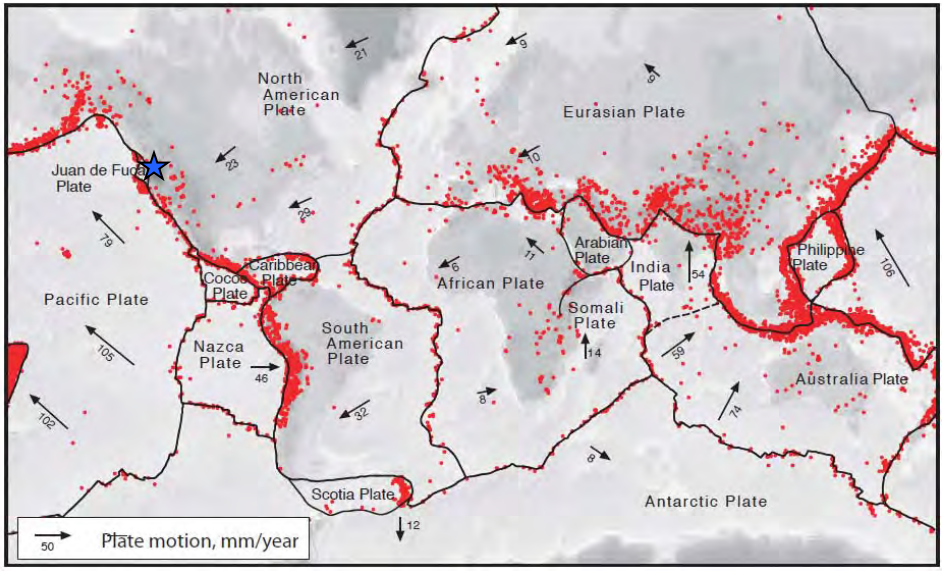


Large Earthquake Locations

Large earthquakes occur primarily along tectonic plate margins.



Tectonic plates are moving at about the rate that fingernails grow.



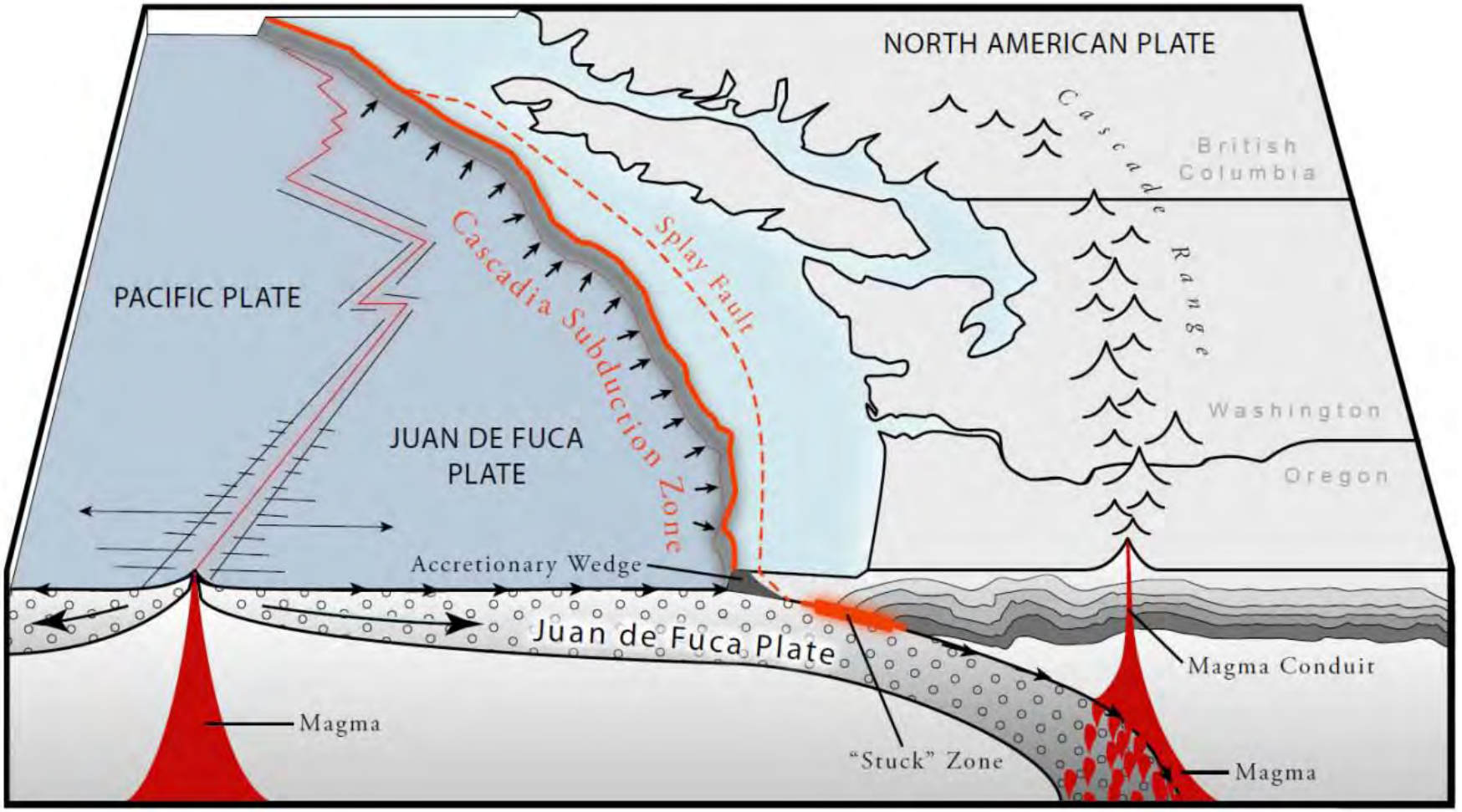
Topography Reflects Tectonic Plates

Plates Move in 3 Ways:

- **Slide Past**
- **Spread Out**
- **Dive Under (Subduction)**

Cascadia Subduction Zone (CSZ)

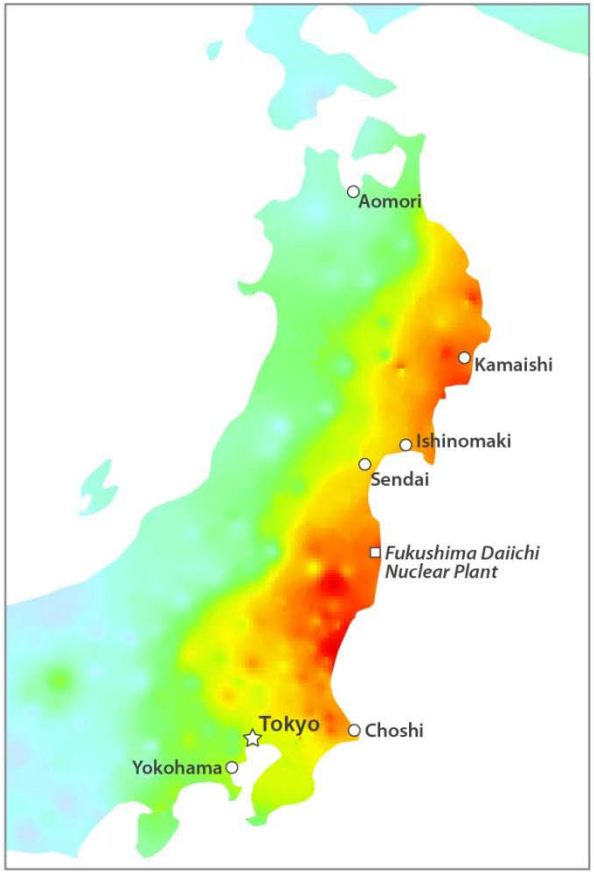
North American Plate Overrides Juan de Fuca Plate Along Cascadia Subduction Zone at a rate of 1.5 inches/year



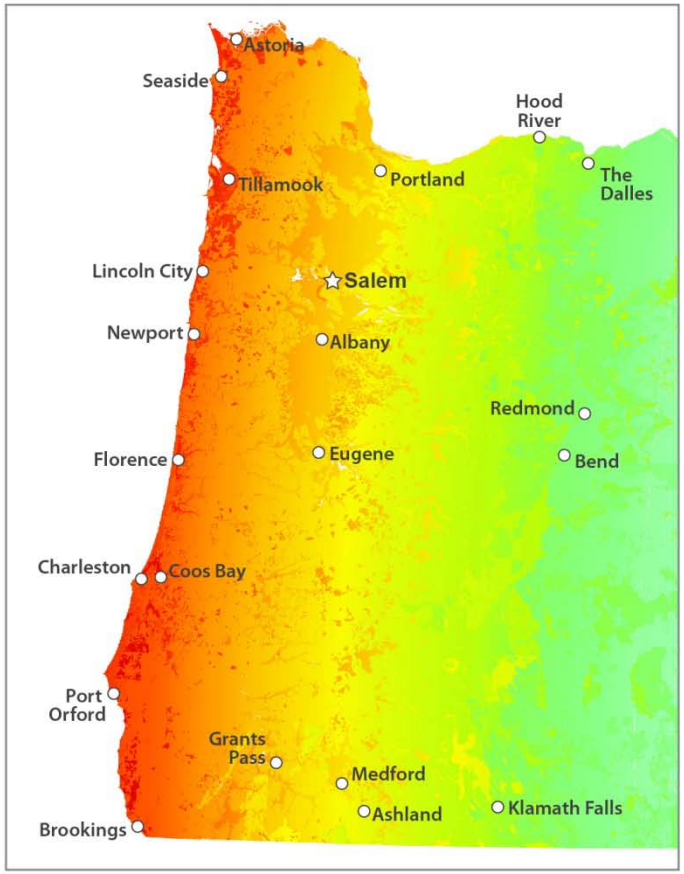
Subduction Zones – Japan vs. Oregon

ShakeMap Comparison

ShakeMap for March 11, 2011 Tohoku M9 Earthquake



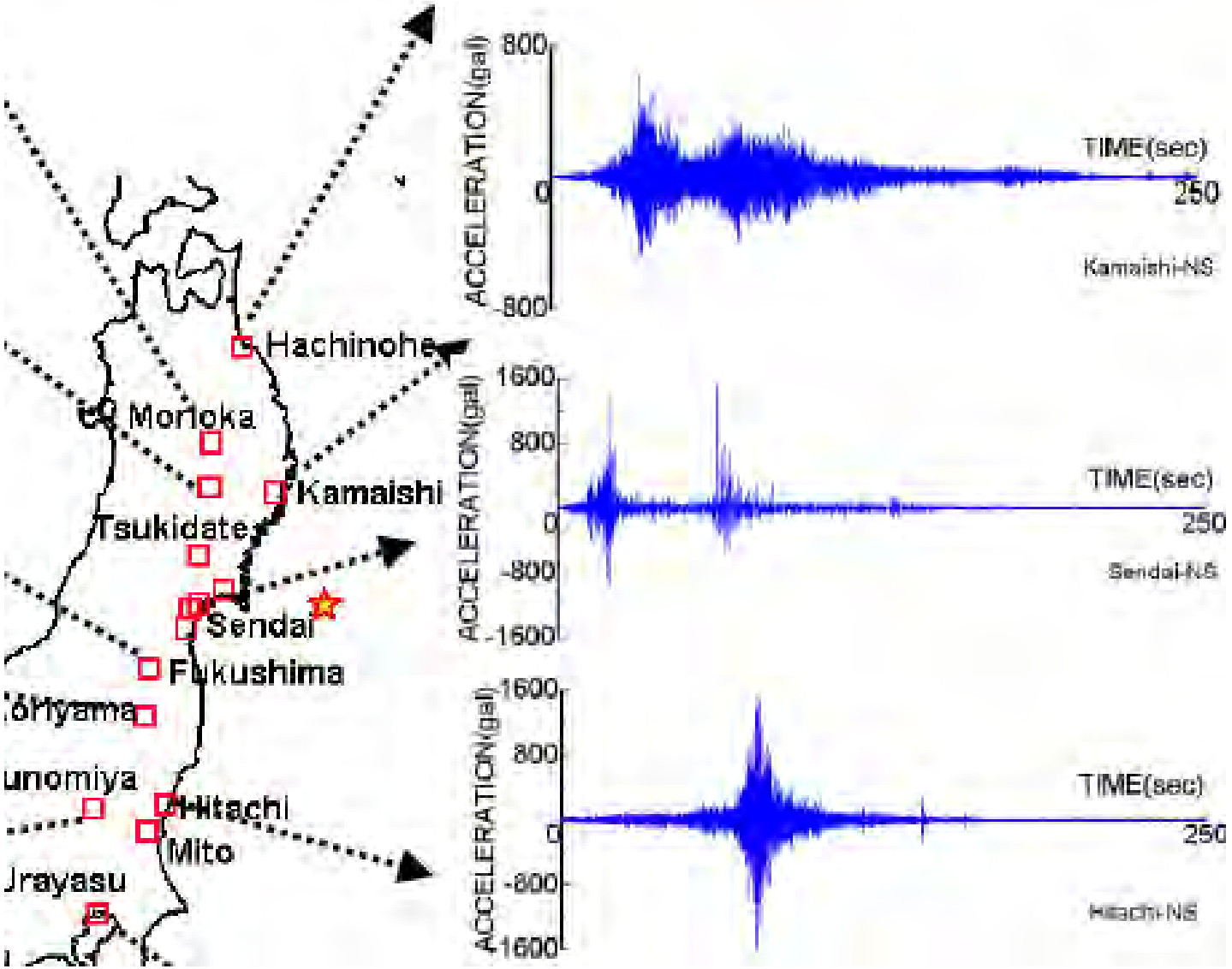
ShakeMap for Simulated M9 Cascadia Earthquake



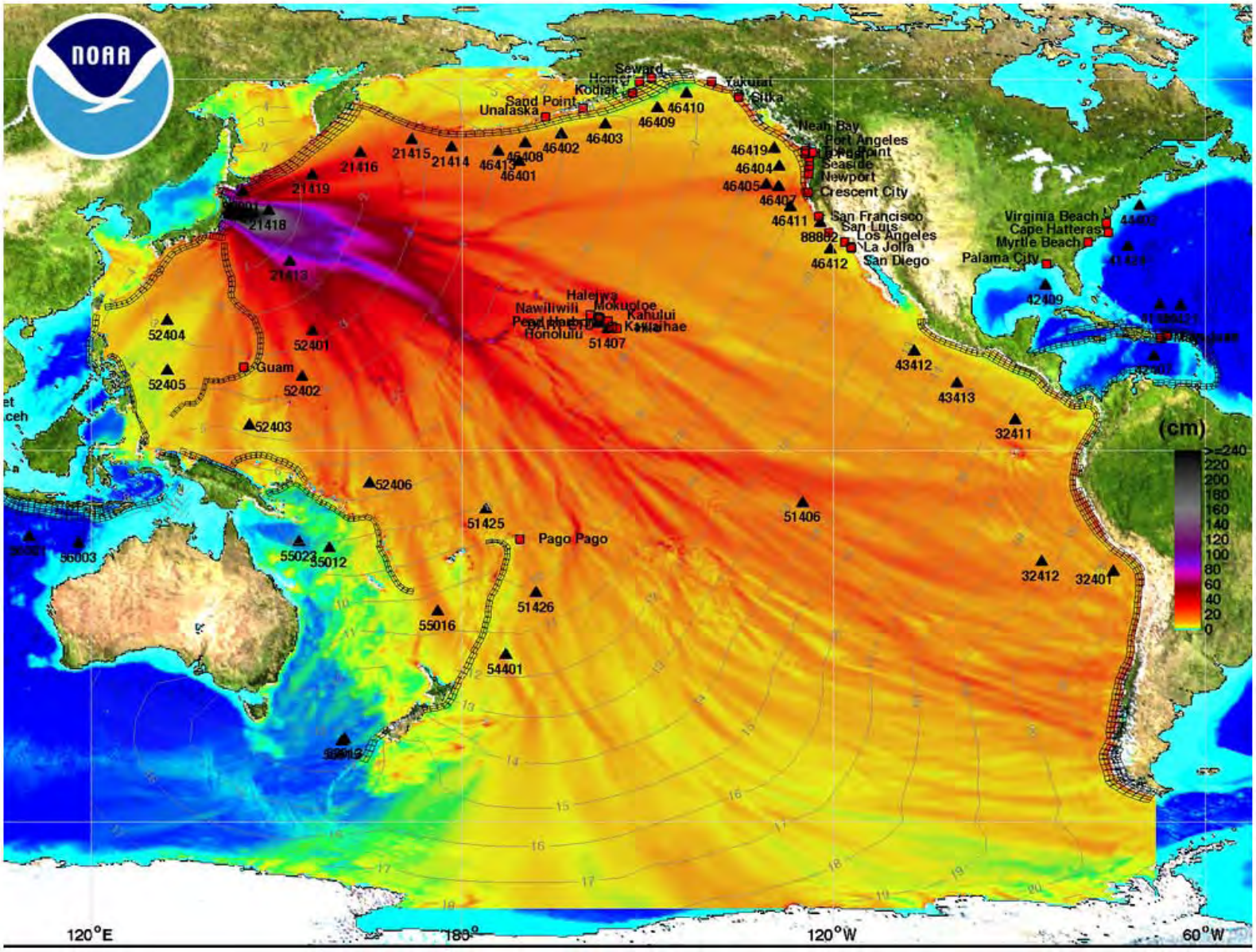
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

How long did the ground shake?

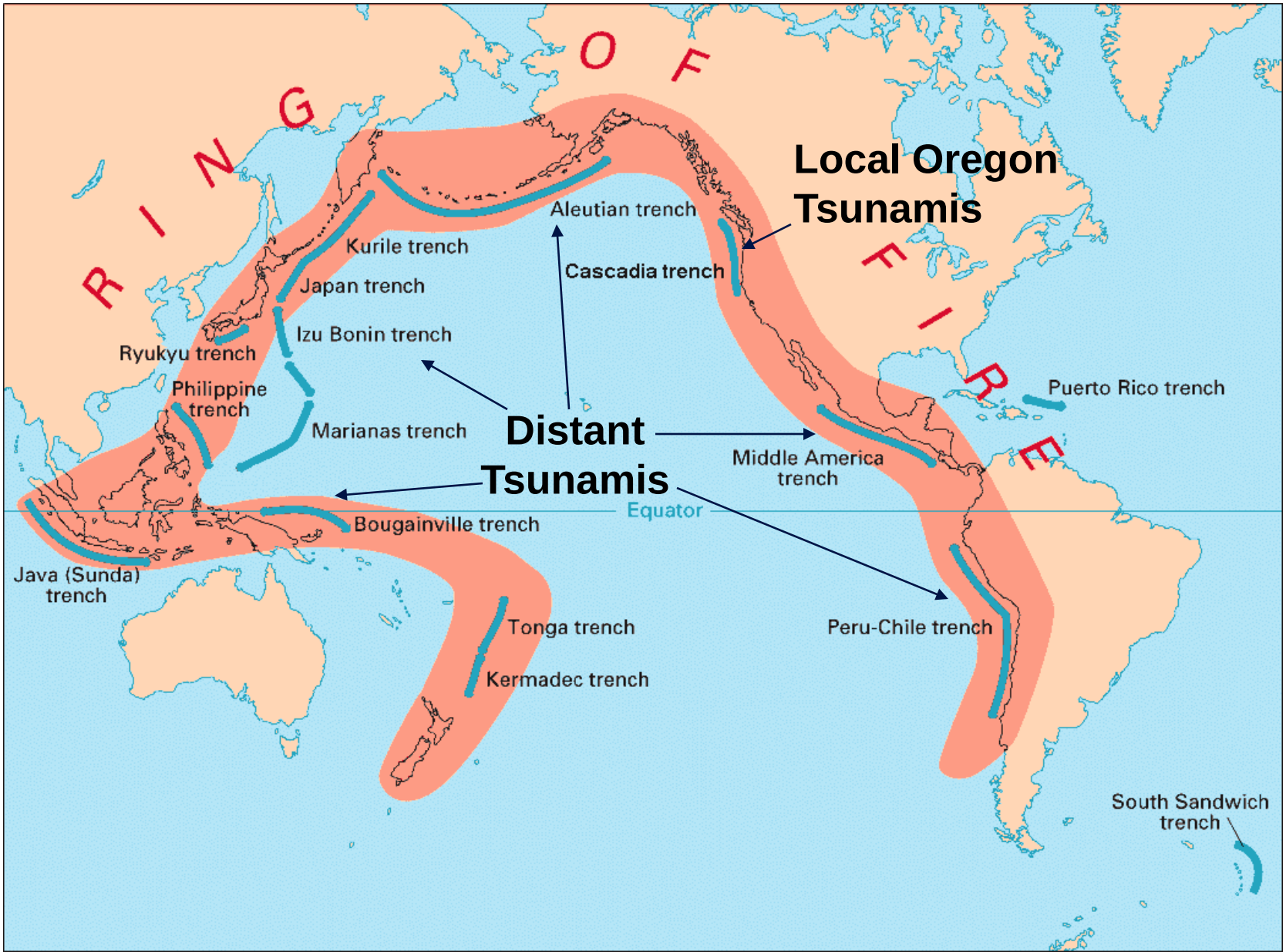
3 Minutes!!



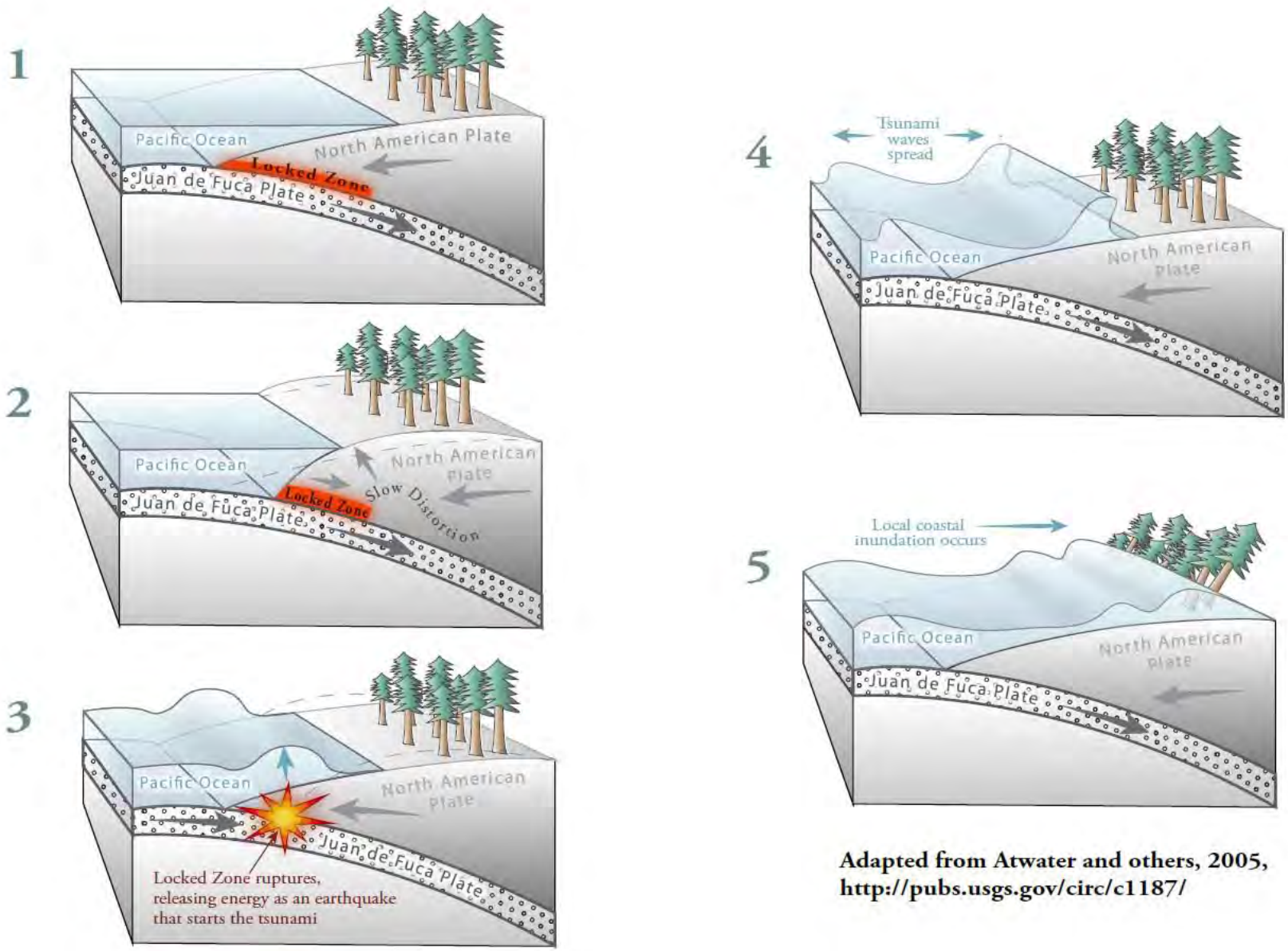
March 11, 2011 Tsunami



Subduction Zone Tsunami Sources



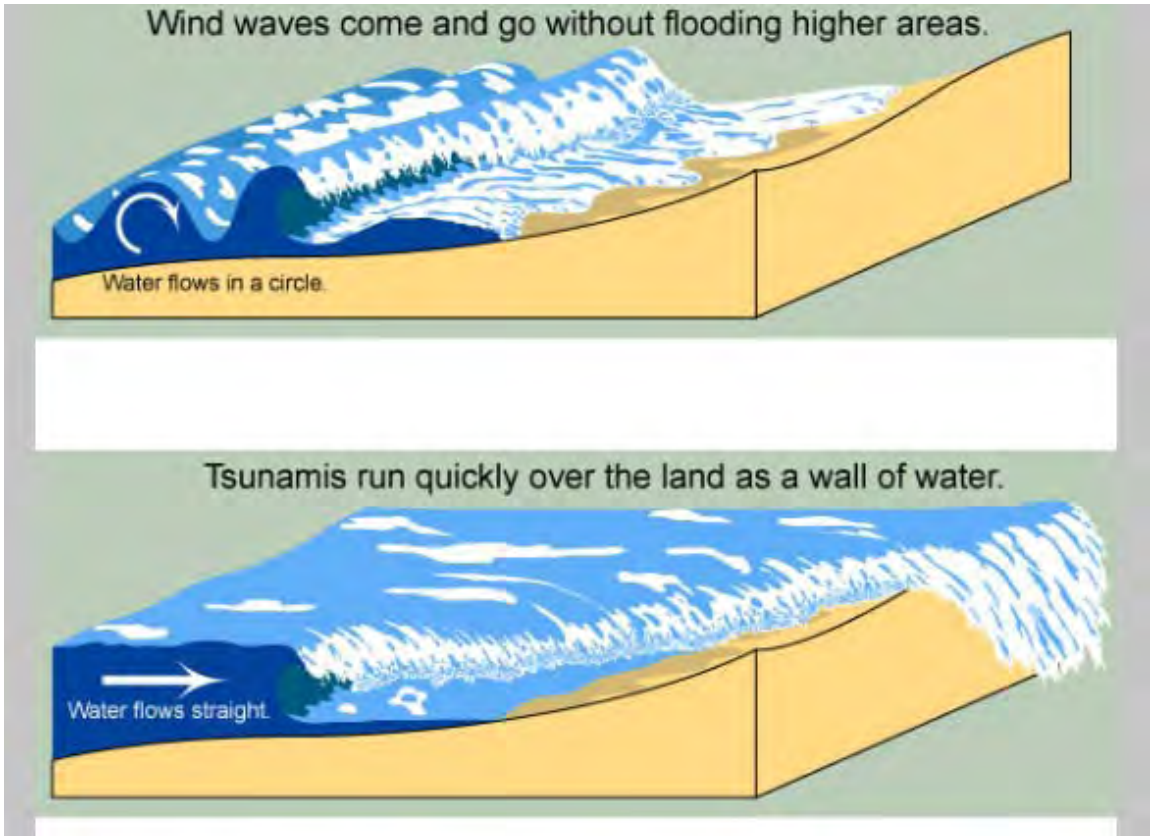
How are tsunami's created?



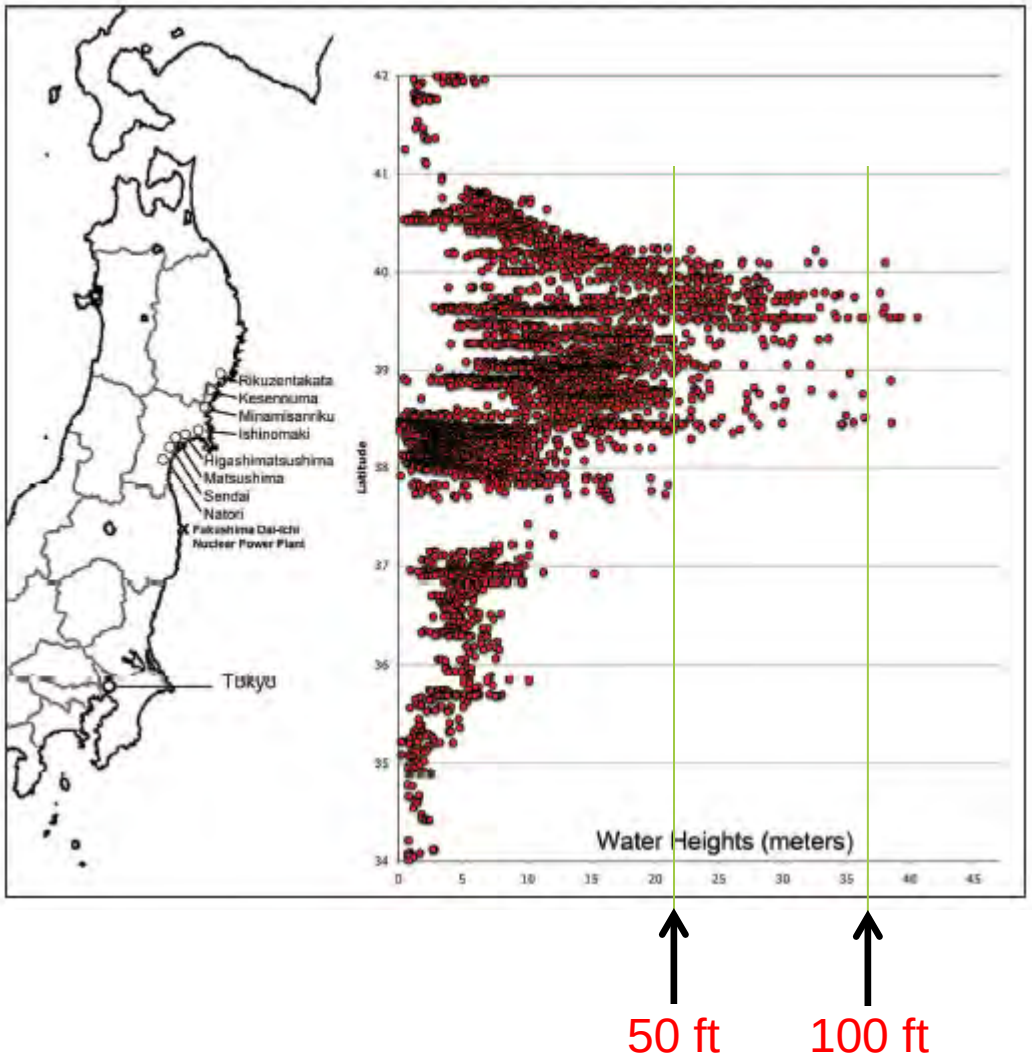
Adapted from Atwater and others, 2005, http://pubs.usgs.gov/circ/c1187/

Tsunamis are more than a “Wave”

- Waves break on shore
- Tsunamis are a higher ocean surface that just keep coming



Tsunami Water Elevations



- **First tsunami surges arrived in 15 minutes (Japan, 2011)**

Lessons from March 11, 2011

CASCADIA

News & information from the Oregon Department of Geology and Mineral Industries WINTER 2012

A similar earthquake and tsunami are in our future—

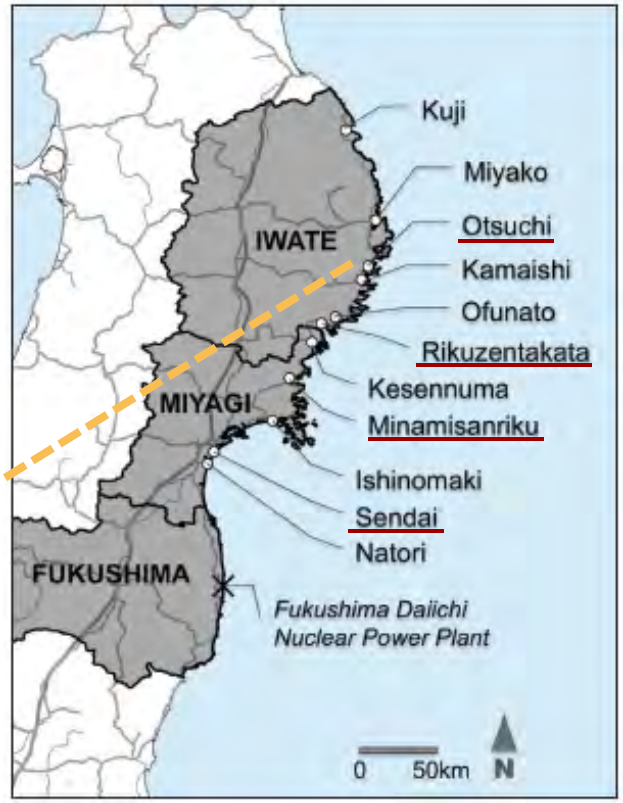
The 2011 Japan earthquake and tsunami: Lessons for the Oregon Coast

The March 11, 2011 Tōhoku, Japan earthquake was a magnitude 9.0 subduction zone earthquake 80 miles off the coast of Japan. The earthquake triggered a devastating tsunami that inundated the northeast coast of Japan within minutes. The quake and tsunami had massive societal impacts: according to the National Police Agency of Japan, 15,845 were confirmed killed and another 3,380 are still missing; thousands more were injured. Over 1.1 million buildings were damaged or destroyed, including 6,751 school buildings and more than 300 hospitals. The tsunami created 24 million tons of waste debris. The reinsurance company Munich Re† estimated economic losses at US$210 billion, excluding the subsequent nuclear accident. **Is Oregon prepared for an earthquake like the one in Japan? What happened? Can it happen here? What can we do to prepare?***

Follow the trail of the Tōhoku tsunami!

An aerial view of damage to Ōtsuchi, Iwate prefecture, Japan on March 15, 2011, after the magnitude 9.0 Tōhoku earthquake and subsequent tsunami devastated the area; 11.6% (1,378 people) of the exposed population were killed or are missing. In Iwate prefecture, 4,667 were killed and 1,363 remain missing. *(U.S. Navy photo by Mass Communication Specialist 3rd Class Alexander Tidd/Released)*

*National Policy Agency of Japan: http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf
†Munich Re: http://www.munichre.com/en/media_relations/press_releases/2012/2012_01_04_press_release.aspx



Defenses Failed

Pine Forests

Sea Walls

Infrastructure Failed

Overturned and Underwater Central Pier

- Tsunami wave height reached 39 feet
- Six spans of this bridge washed from 1,000 to 1,300 feet away
- Railroads no longer usable

Vertical Evacuation Failed

Figure 8. *The approximate inundation zone in Minimisanriku Town. The tsunami surges destroyed the town center and went up the narrow Hachiman River (center) and the Sakura River (on left) and the Oretate River (on right). Black arrow is 2 km long. (A) marks the location of the disaster management building shown in Figure 10 and (B) shows the tsunami evacuation building in*

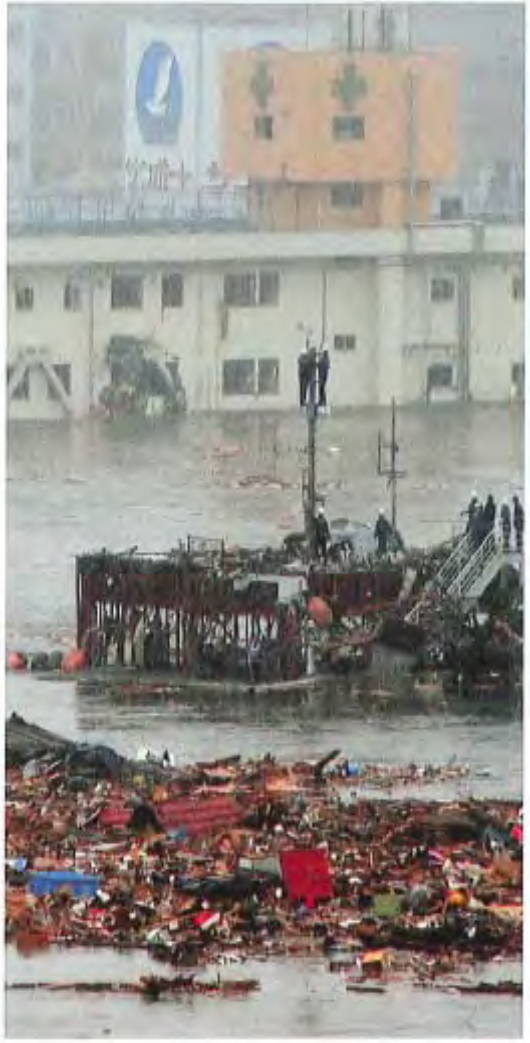
In this City: 31 of 80 designated tsunami evacuation centers destroyed

Disaster Management HQ

Go to High Ground!

Disaster Management HQ

30 officials went to the roof…11 survived



Wood Buildings Perform Well in EQ, But Poorly in Tsunami

Wood Houses Destroyed By Water Depth & Velocity

- **At 6.5 to 8 feet deep: 72% destroyed**
- **65% of “destroyed buildings” were simply washed away**

Reinforced Concrete Buildings Survive Better Than Wood

…but not always

Tsunami water carries an enormous amount of debris

Before Tsunami at Sendai

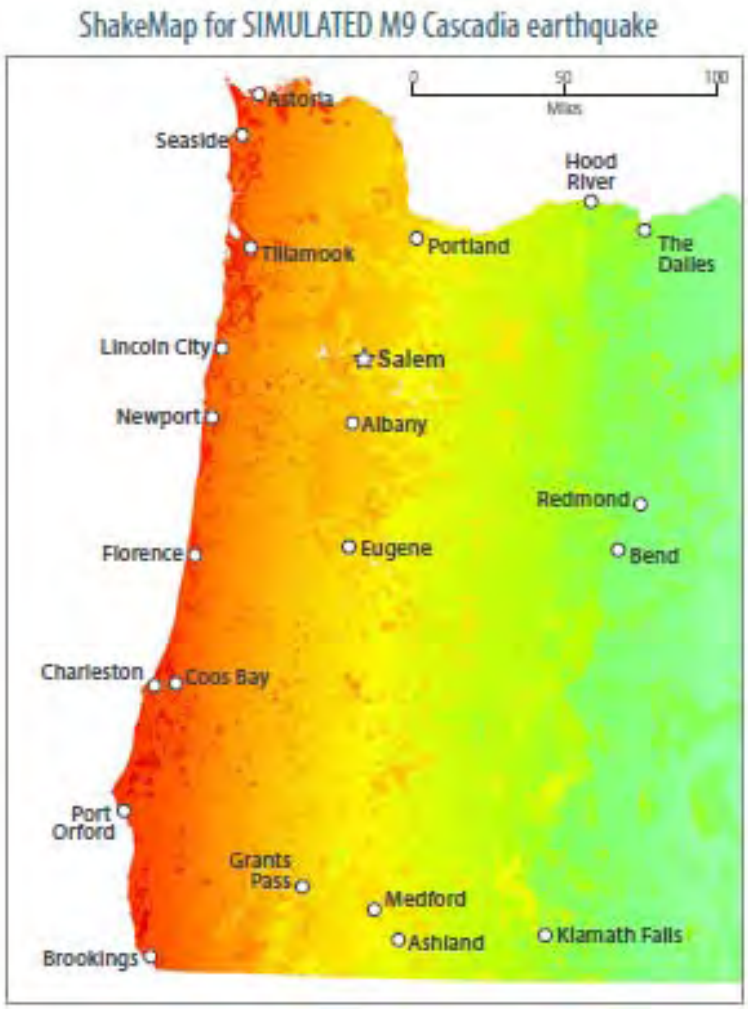
Arahama in Sendai

After Tsunami at Sendai

Arahama in Sendai

What should you expect in Oregon?

- **M9.0 Great Earthquake**
  - **Western Oregon will experience strong to violent shaking lasting for 2 or more minutes**
  - **This experience will be unmistakable**
  - **Bridges will fail; Expect to walk to high ground**
  - **15 to 30 minutes later = start of tsunami**
  - **Tsunami waves will continue for at least 4 hours**



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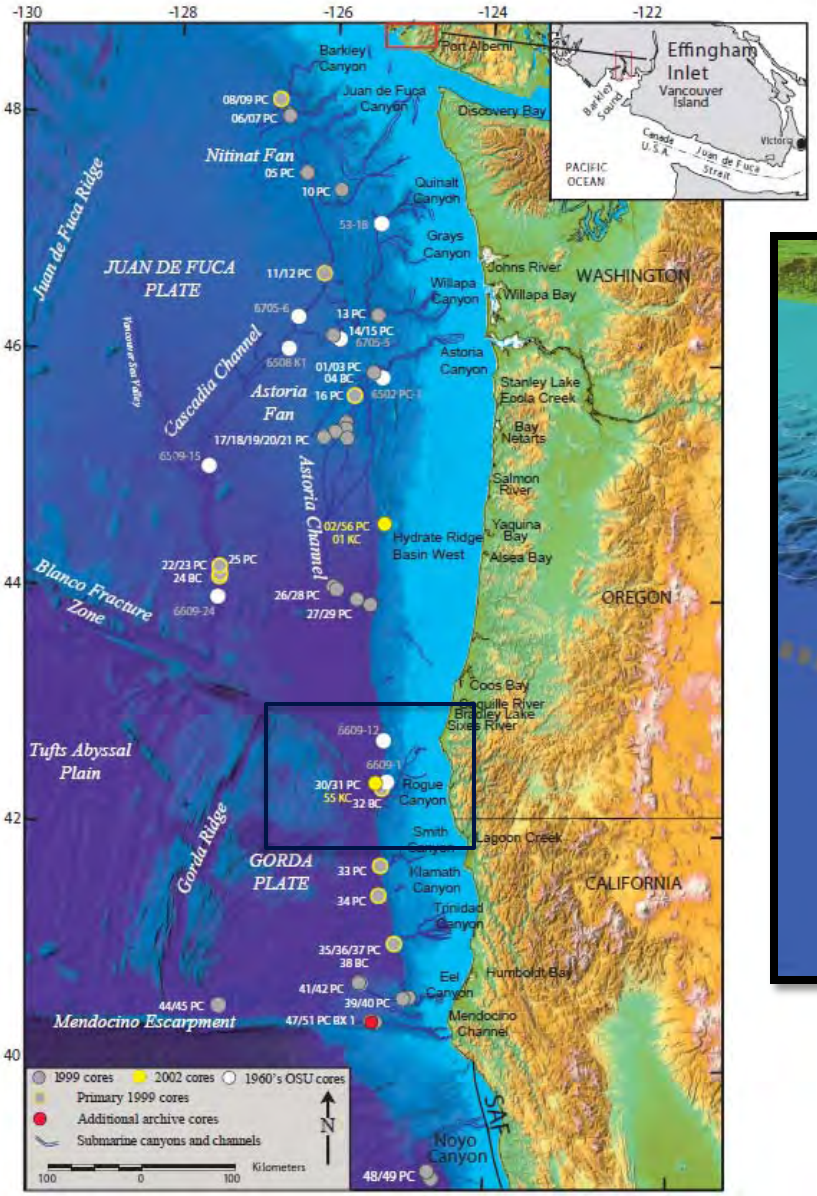
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Lessons from Japan

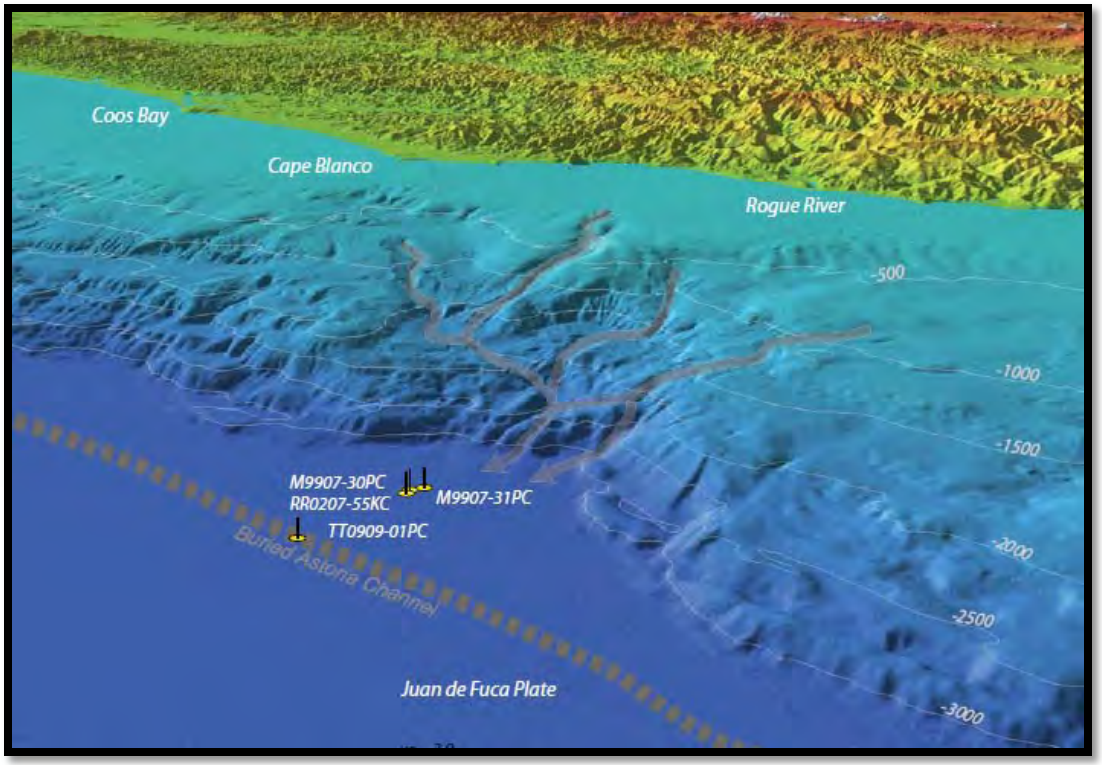
- Prepare your evacuation plan and "go bag" **now**
- When the ground shakes hard for a long time, **evacuate immediately** to high ground on foot
- Vertical evacuation is a "**last resort**" option
- Tsunami waves will arrive for several hours
  - First wave *may not* be the largest
- Wood buildings will **not survive**
  - Not all concrete or steel frame buildings will survive
- Help may not arrive for several to many days

You *will survive* if you prepare and take action!

10,000-year History of Oregon Earthquakes



Locations of soil core samples taken off the Oregon coast



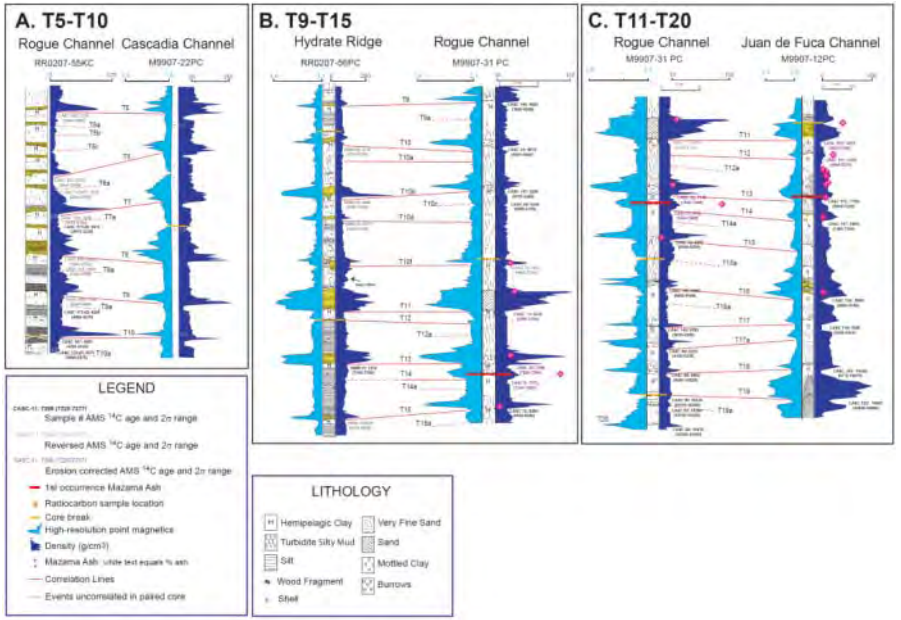
Offshore Landslides Record Earthquakes

- Offshore landslides that have been generated from CSZ earthquakes produce turbidites.

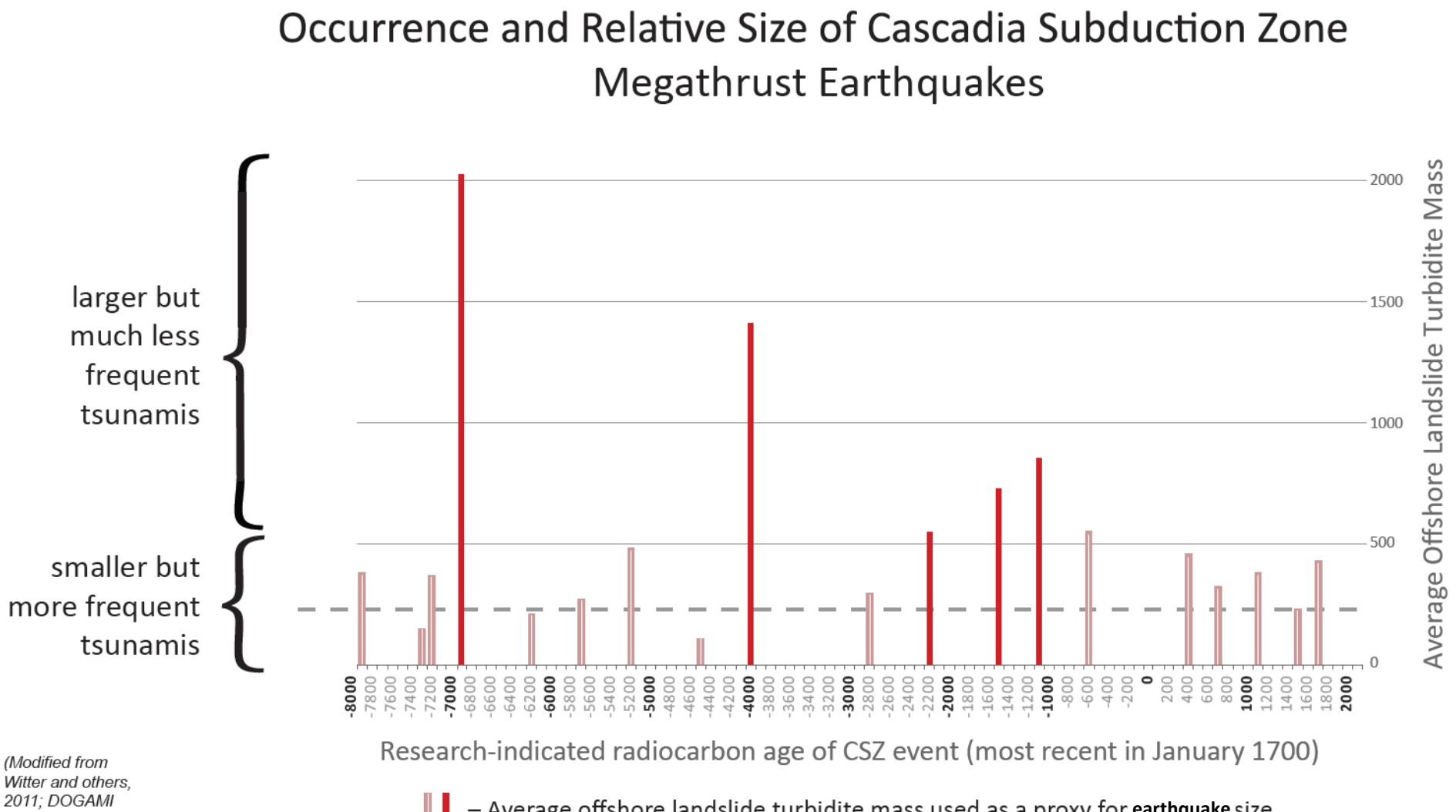
- These turbidites can be measured from core samples like the one pictured here.

- The measuring of this mass, in addition to other sand deposits left in onshore estuaries, allow scientists to date and measure historical CSZ events.

- These historical CSZ events are then correlated between samples to create a comprehensive history of cascadia subduction zone events.

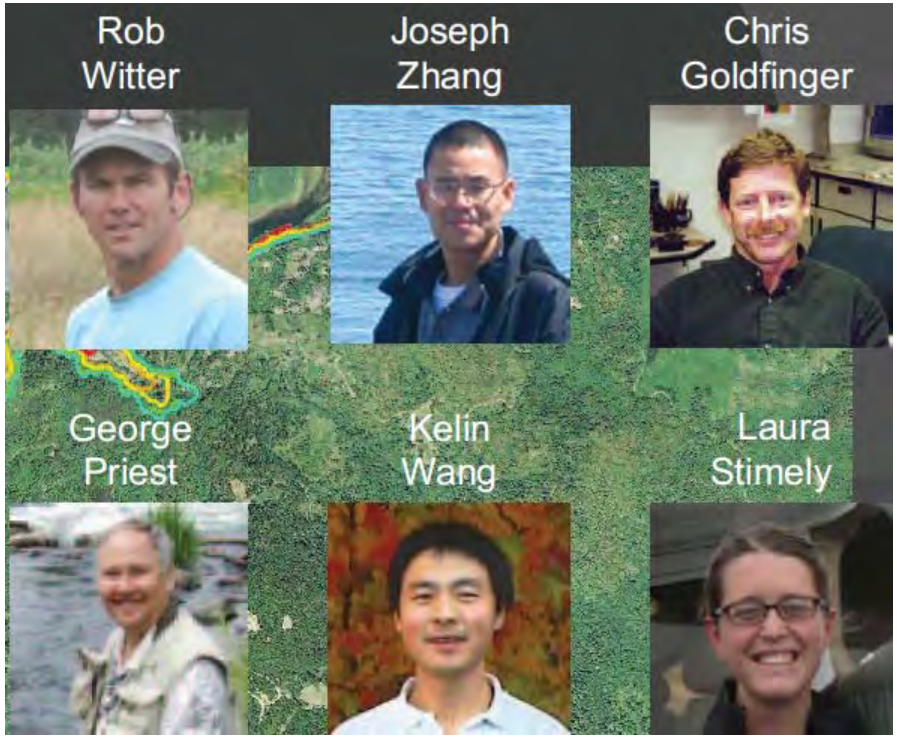


19 CSZ Events in Past 10,000 Years



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

Science Team Modeled Many Tsunami Scenarios



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5 Final Scenarios (S, M, L, XL, XXL)

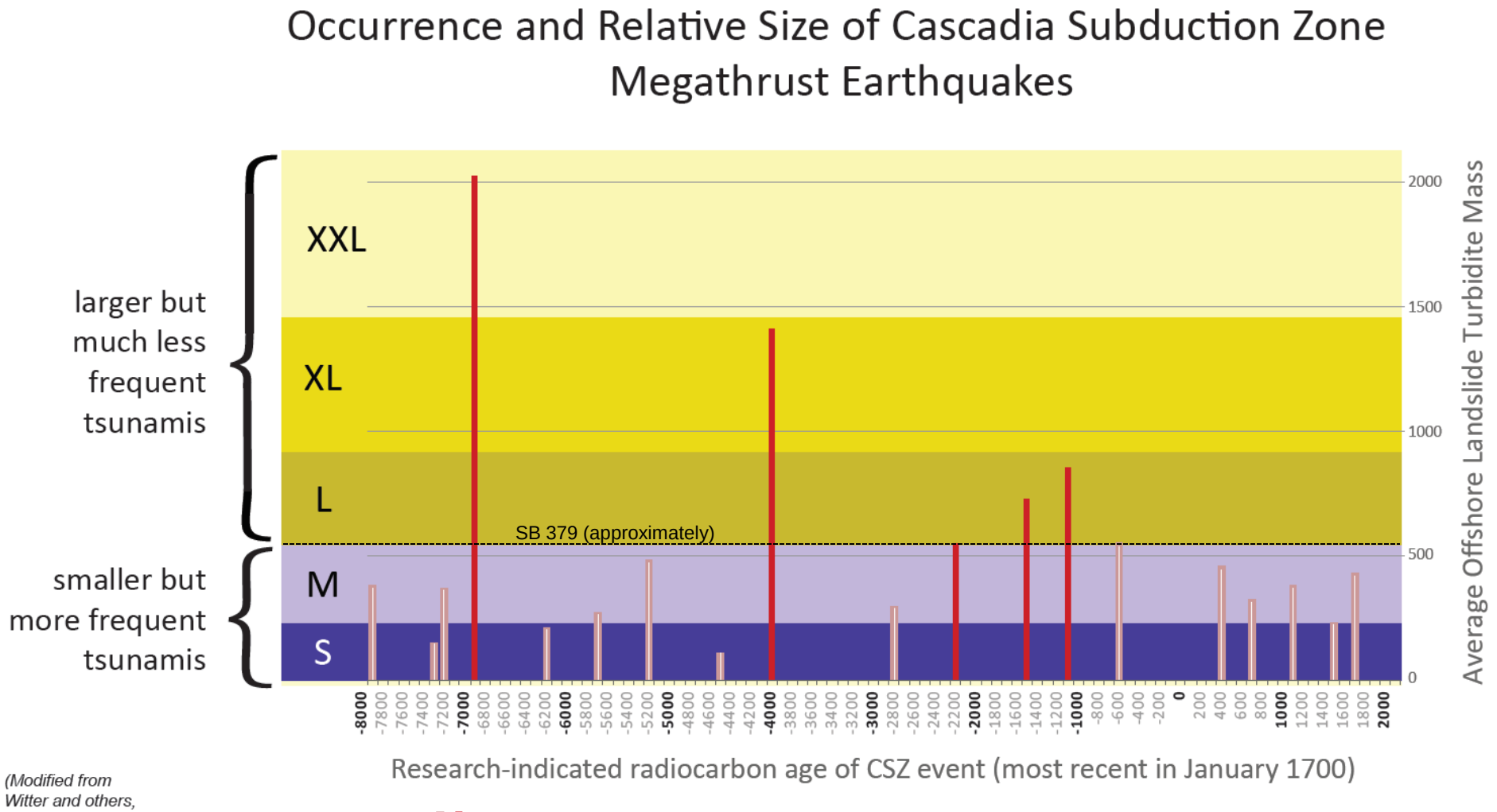
Reference:

Simulating tsunami inundation at Bandon, Coos County, Oregon, using hypothetical Cascadia and Alaska earthquake scenarios

Authors: Witter, R.C., Zhang, Y., Wang, K., Priest, G.R., Goldfinger, C., Stimely, L.L., English, J.T., and Ferro, P.A.

Oregon Department of Geology and Mineral Industries Special Paper 43

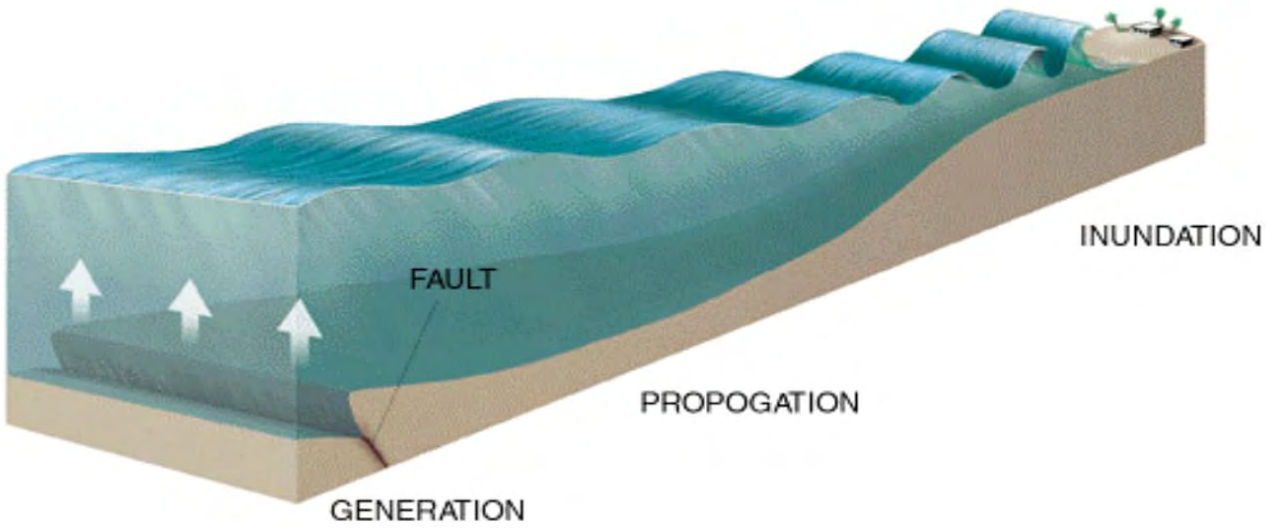
Historical Event Size & Frequency Relate to the 5 Scenarios



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

DOGAMI Tsunami "T-Shirts"

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



Model Output to DOGAMI

n, x, y, init_D_MHHW, post_D_MHHW, Wet_Dry, Elev_NGVD29, Elev_NAVD88, Elev_MHHW, flow_depth, max_vel, u_comp, v_comp
1,-123.4124823,48.1177411,0.0000000e+00,0.726997,1,0.9362,1.9842,-0.858E-01,0.641197,0.223E-01,-0.217E-01,0.507E-02
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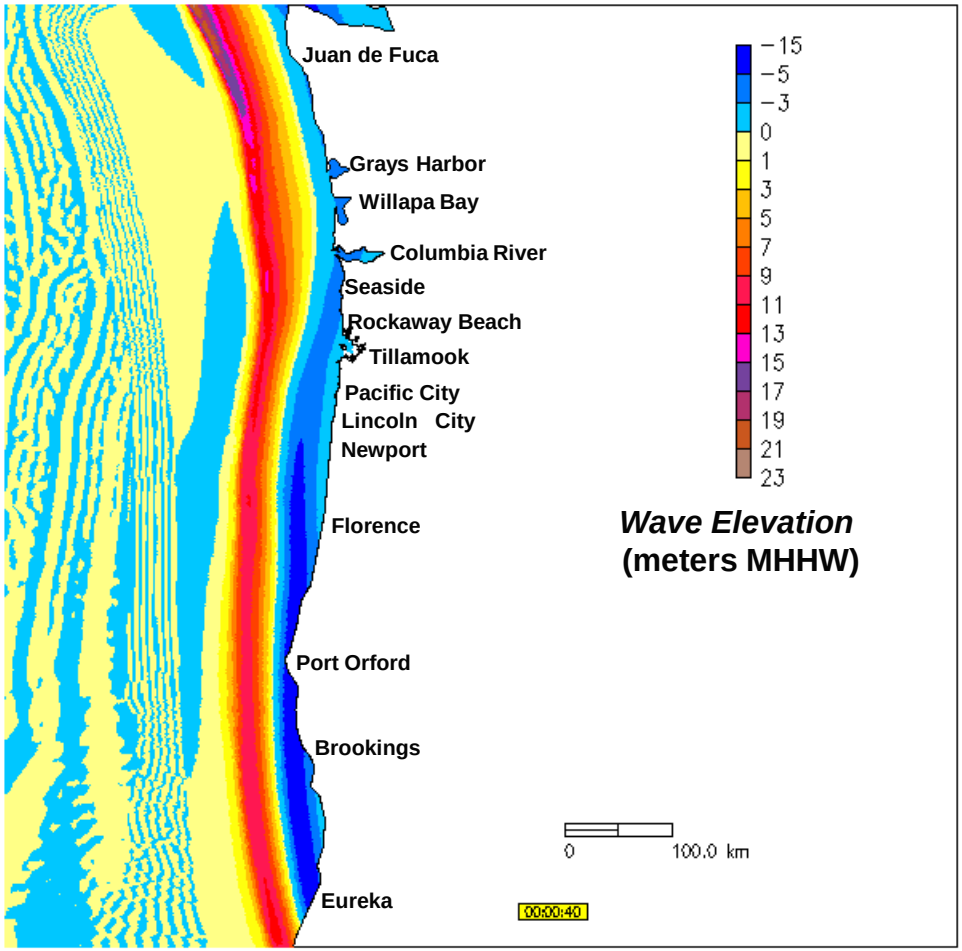
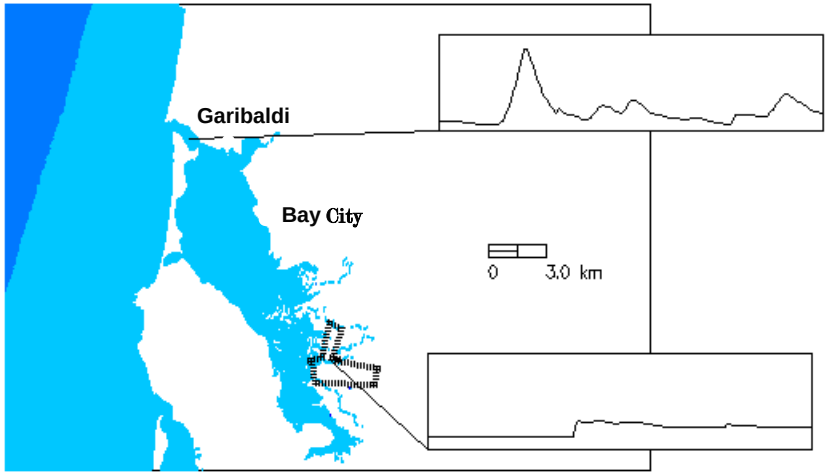
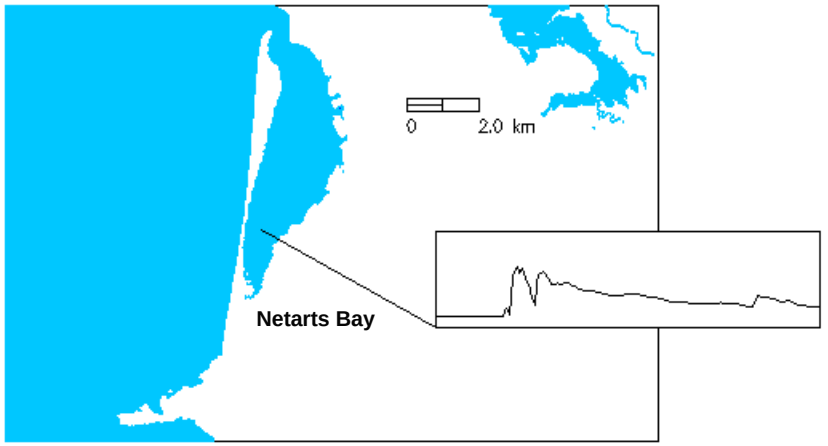
Tsunami Modeling

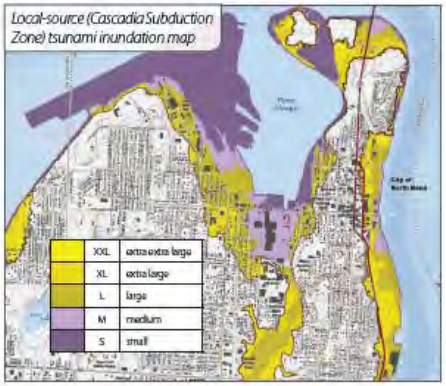
Tillamook Bay - Tsunami Scenario **XXL**







DOGAMI Turns Models to Maps



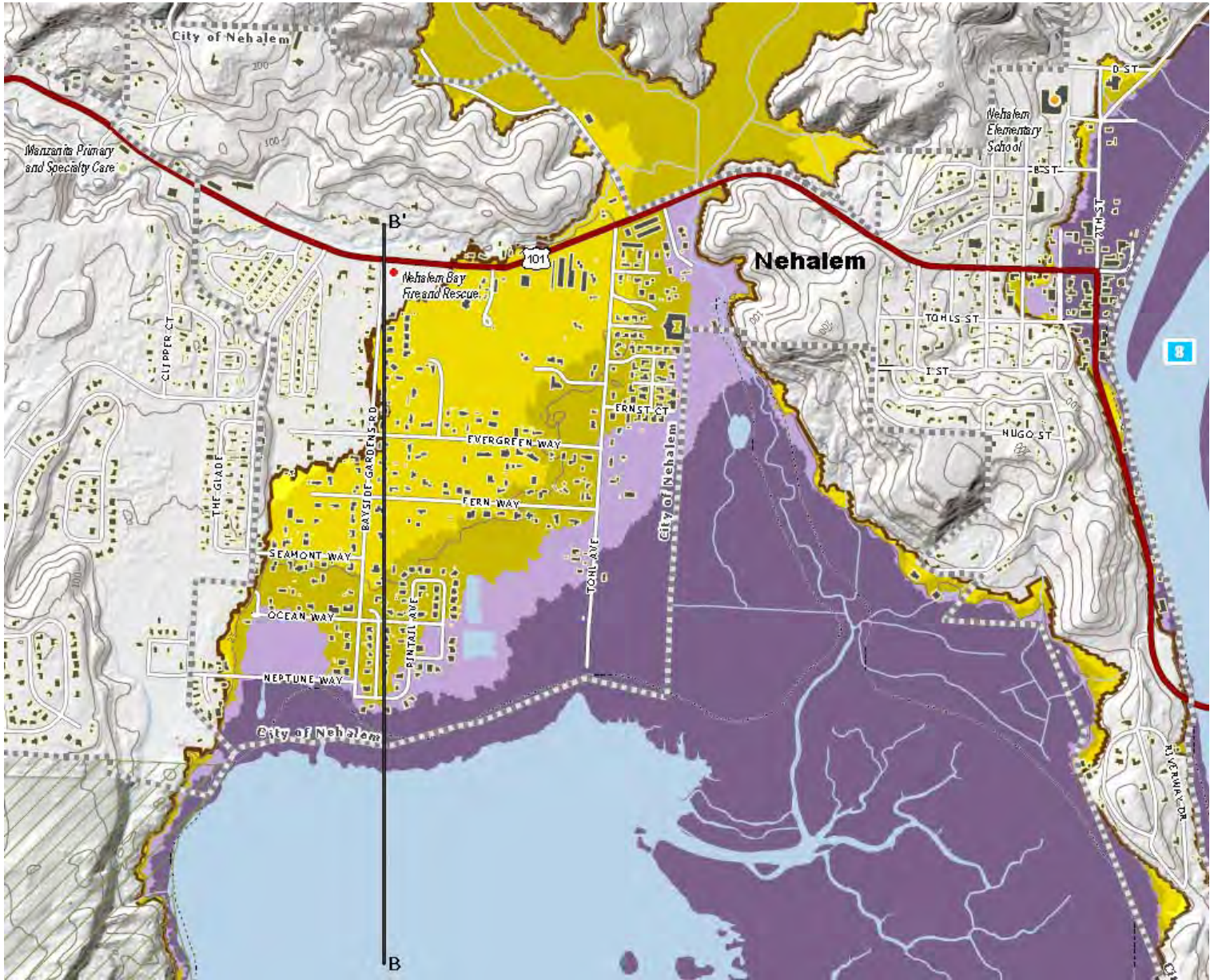
maximum local source (yellow) maximum distant source (orange)

Combine the maximum tsunami scenario from each map ...

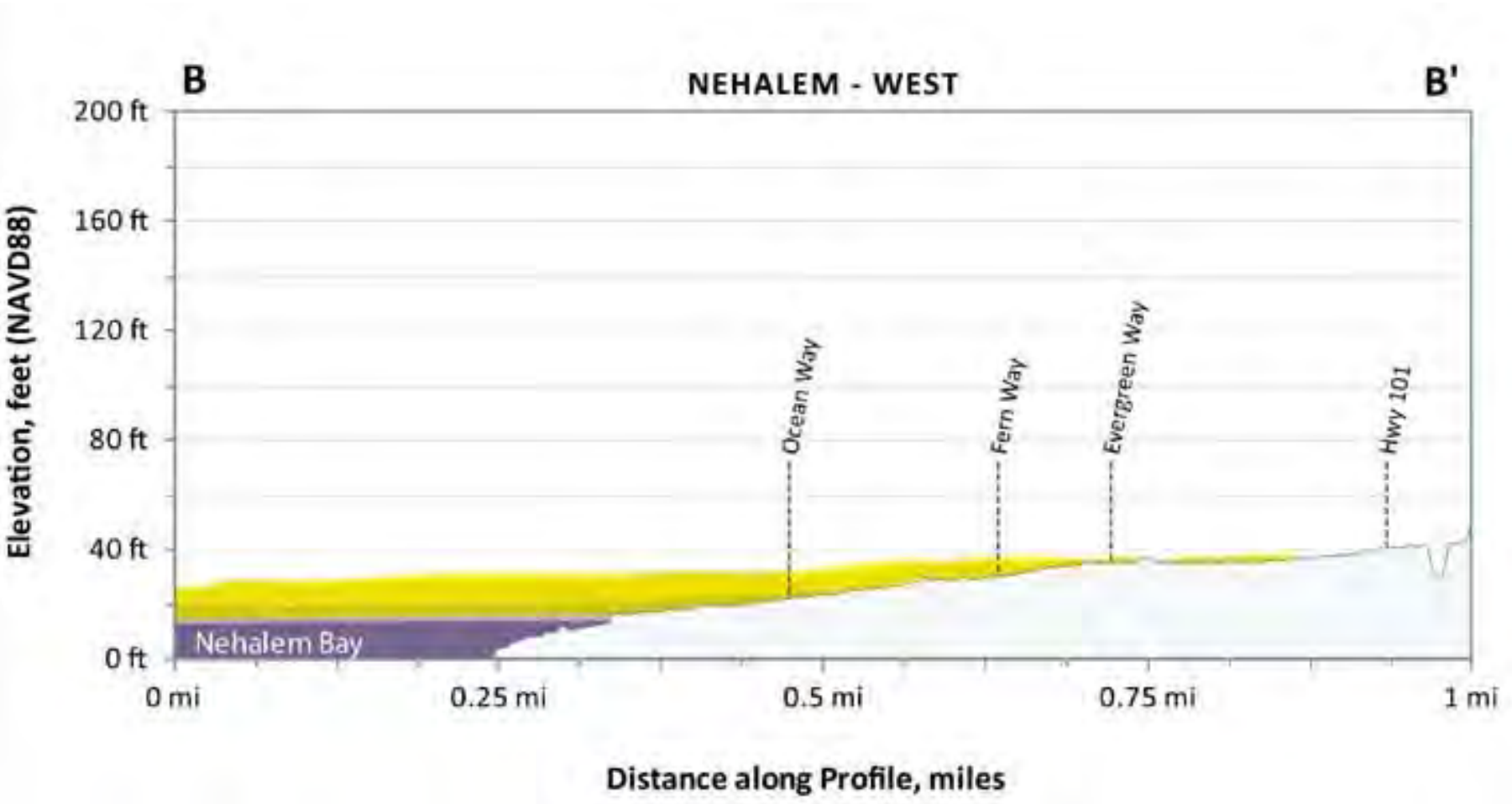
- **Turn Model Output Into Inundation Maps**
  - **5 Local CSZ "Tsunami T-Shirt Scenarios"**
    - **(S, M, L, XL, XXL)**
      - **Occurs at High Tide**
      - **Land Subsidence Taken Into Account**
      - **Maps Include Other Relevant Information such as Wave Time Series, Inundation Exposure, and Wave Elevation Profiles**
  - **2 Distant Alaska Scenarios**
    - **(Alaska 1964 (M9.2) & Alaska Max)**

- **Use XXL (worst local) and Alaska Max (worst distant) for Evacuation Brochures**

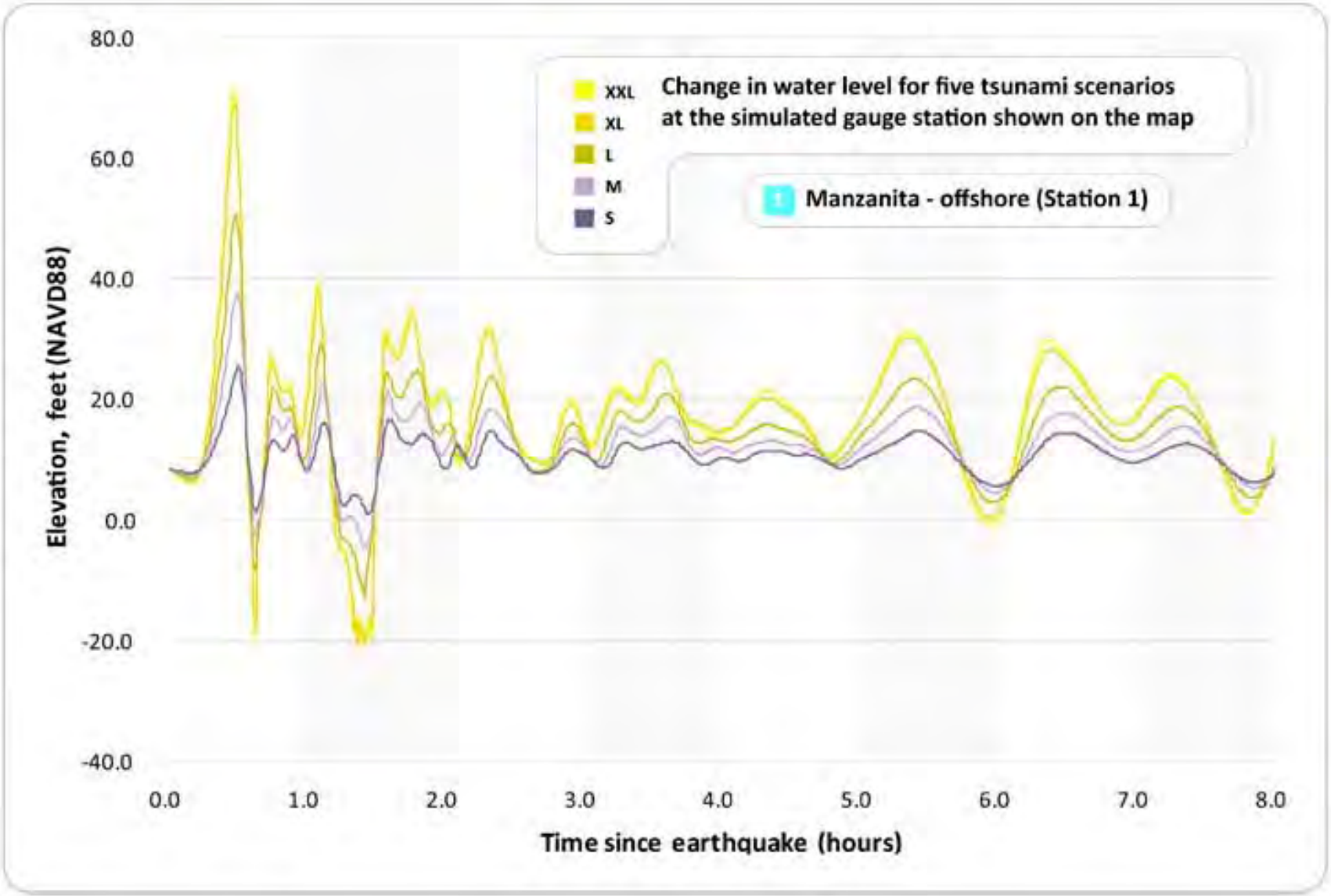
Local CSZ Source Inundation Map



Local CSZ Source Inundation Profile



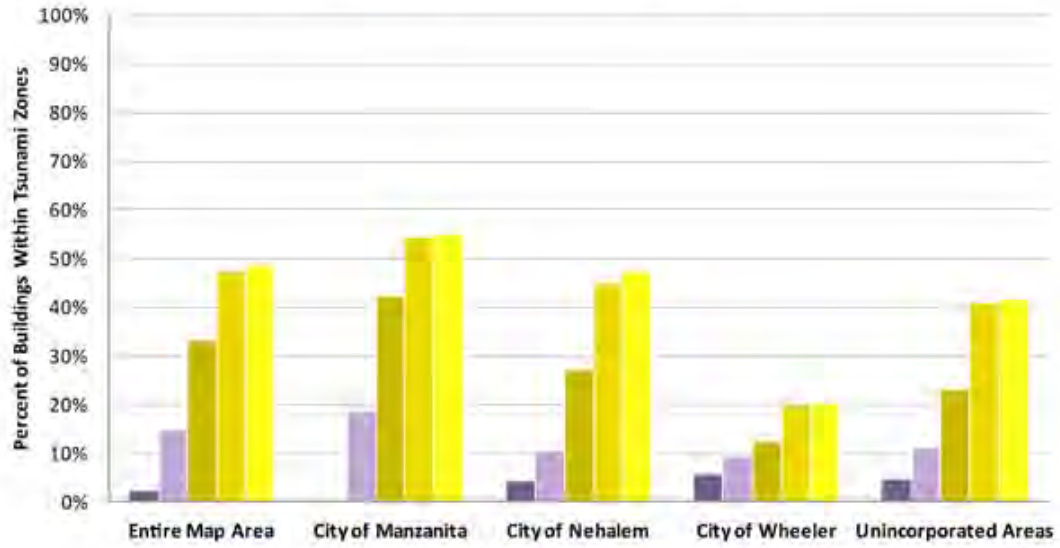
Local CSZ Source Wave Time Series



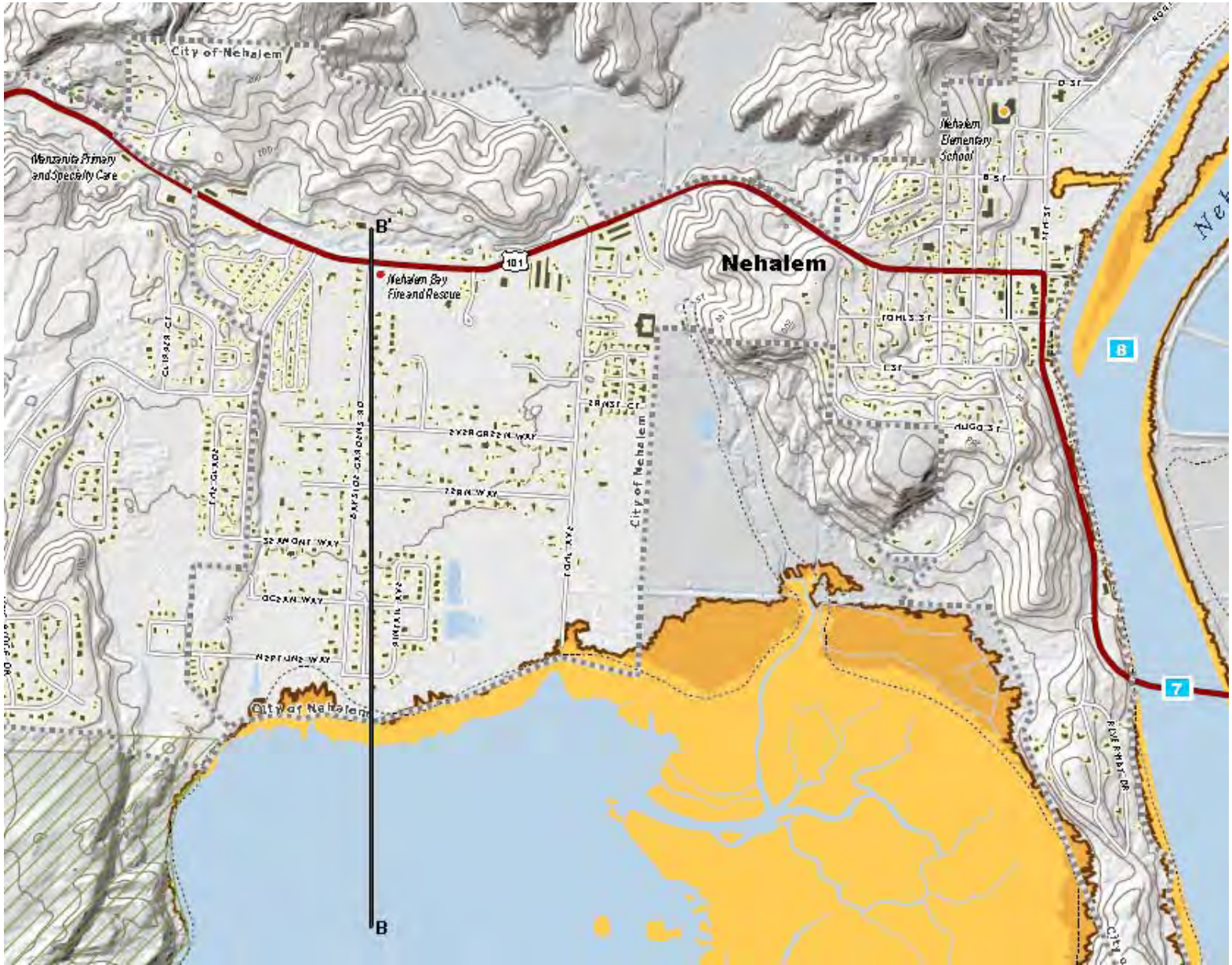
Local CSZ Source Inundation Exposure

	Entire Map Area	City of Manzanita	City of Nehalem	City of Wheeler	Unincorporated Areas
Total Buildings	3,596	1,791	1,056	234	515
Buildings Within Tsunami Zones*					
Small	83	0	46	13	24
Medium	532	340	112	22	58
Large	1,193	756	288	29	120
Extra Large	1,701	970	475	46	210
Extra Extra Large	1,747	985	500	47	215
Percent of Buildings Within Tsunami Zones					
Small	2.3%	0.0%	4.4%	5.6%	4.7%
Medium	14.8%	19.0%	10.6%	9.4%	11.3%
Large	33.2%	42.2%	27.3%	12.4%	23.3%
Extra Large	47.3%	54.2%	45.0%	19.7%	40.8%
Extra Extra Large	48.6%	55.0%	47.3%	20.1%	41.7%

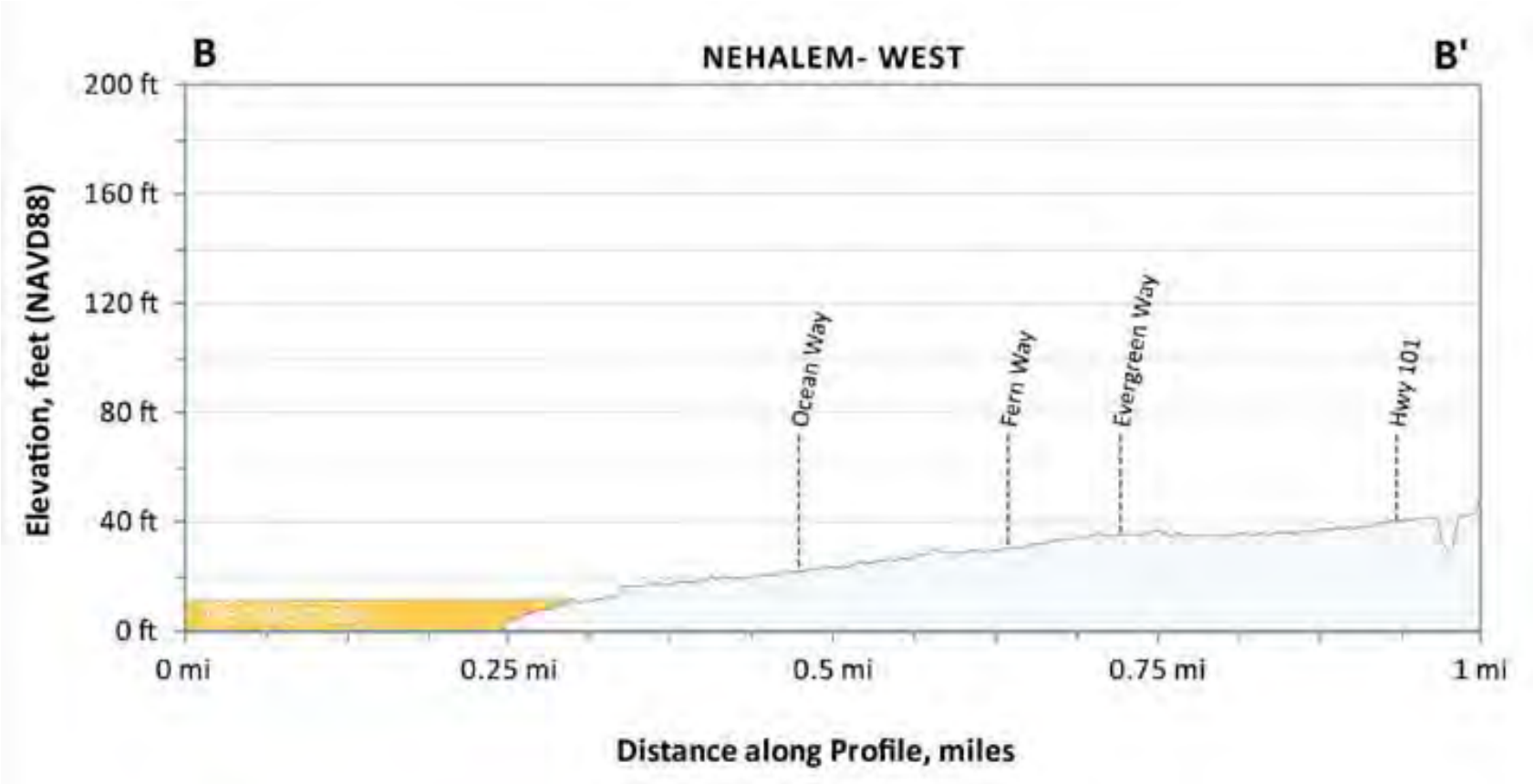
*Building counts shown are based on polygon centroids and are cumulative within the map area.



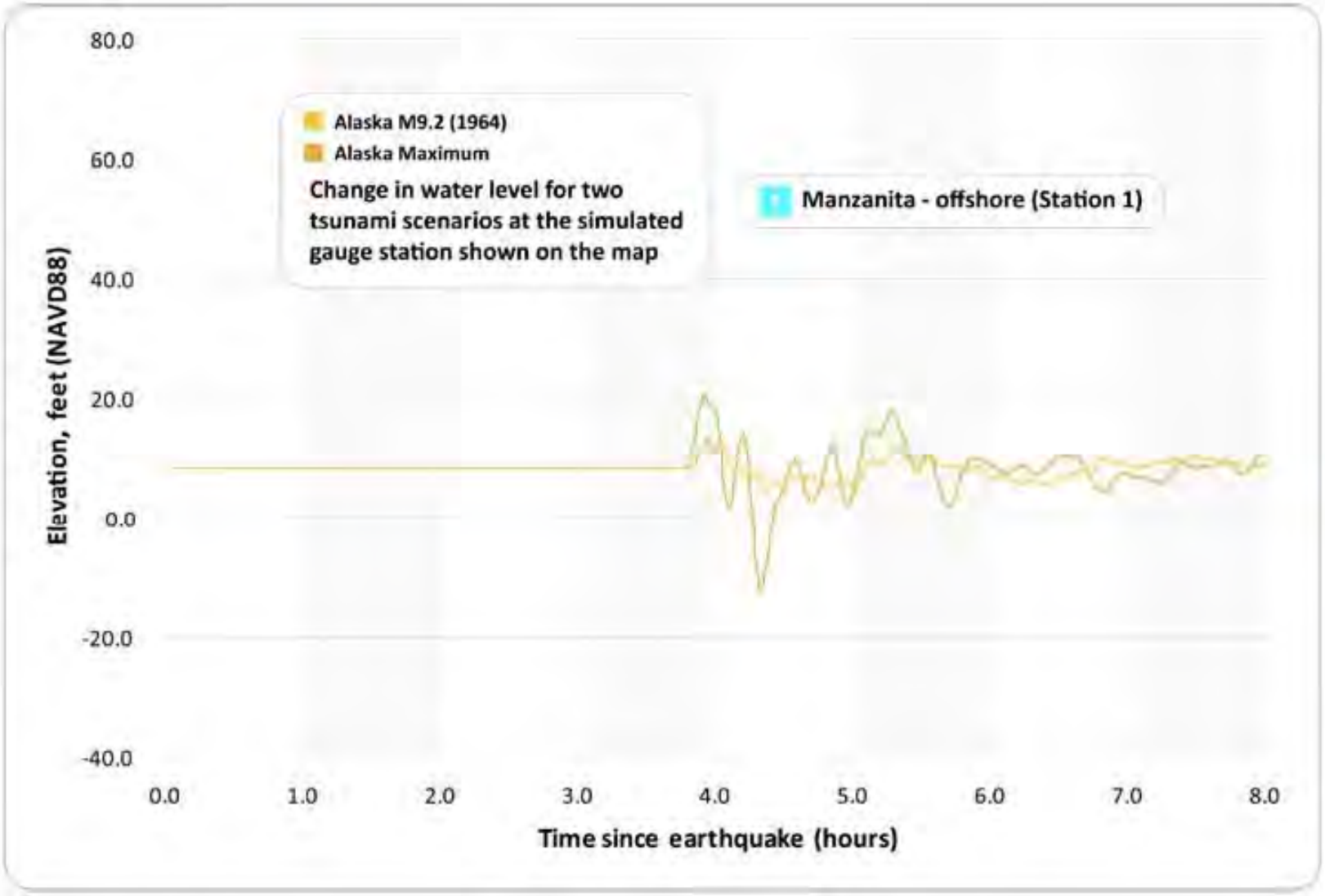
Distant Source Inundation Map



Distant Source Inundation Profile



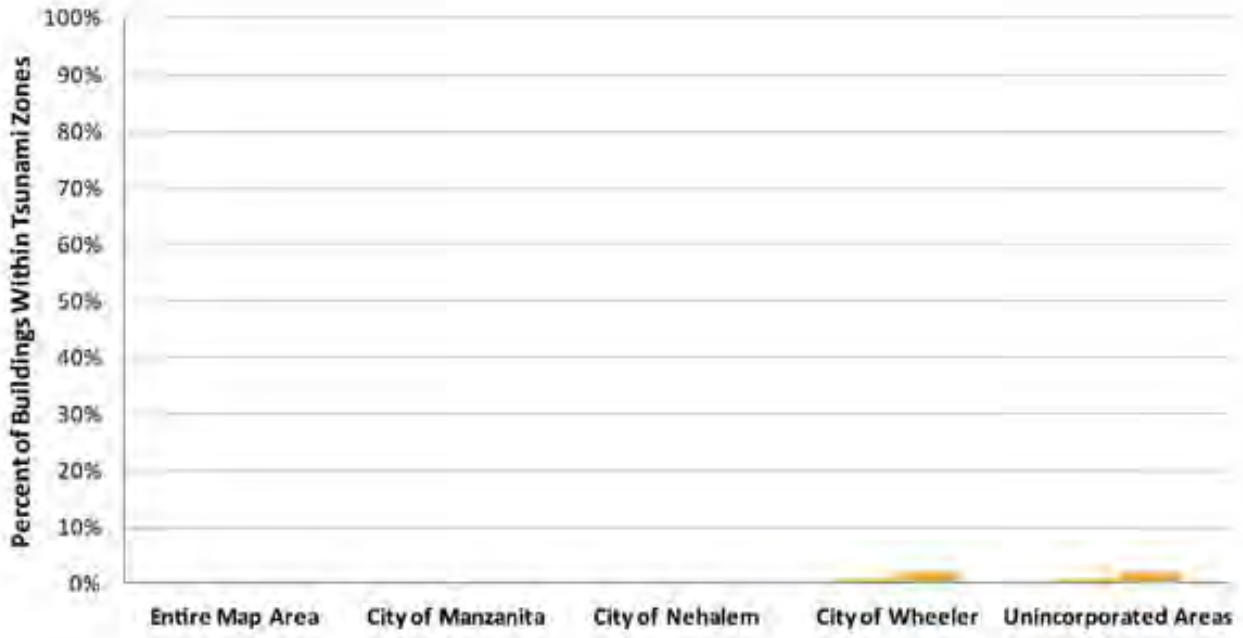
Distant Source Wave Time Series



Distant Source Inundation Exposure

	Entire Map Area	City of Manzanita	City of Nehalem	City of Wheeler	Unincorporated Areas
Total Buildings	3,596	1,791	1,056	234	515
Buildings Within Tsunami Zones*					
Alaska M9.2 (1964)	14	0	5	3	6
Alaska Maximum	21	0	5	5	11
Percent of Buildings Within Tsunami Zones					
Alaska M9.2 (1964)	0.4%	0.0%	0.5%	1.3%	1.2%
Alaska Maximum	0.6%	0.0%	0.5%	2.1%	2.1%

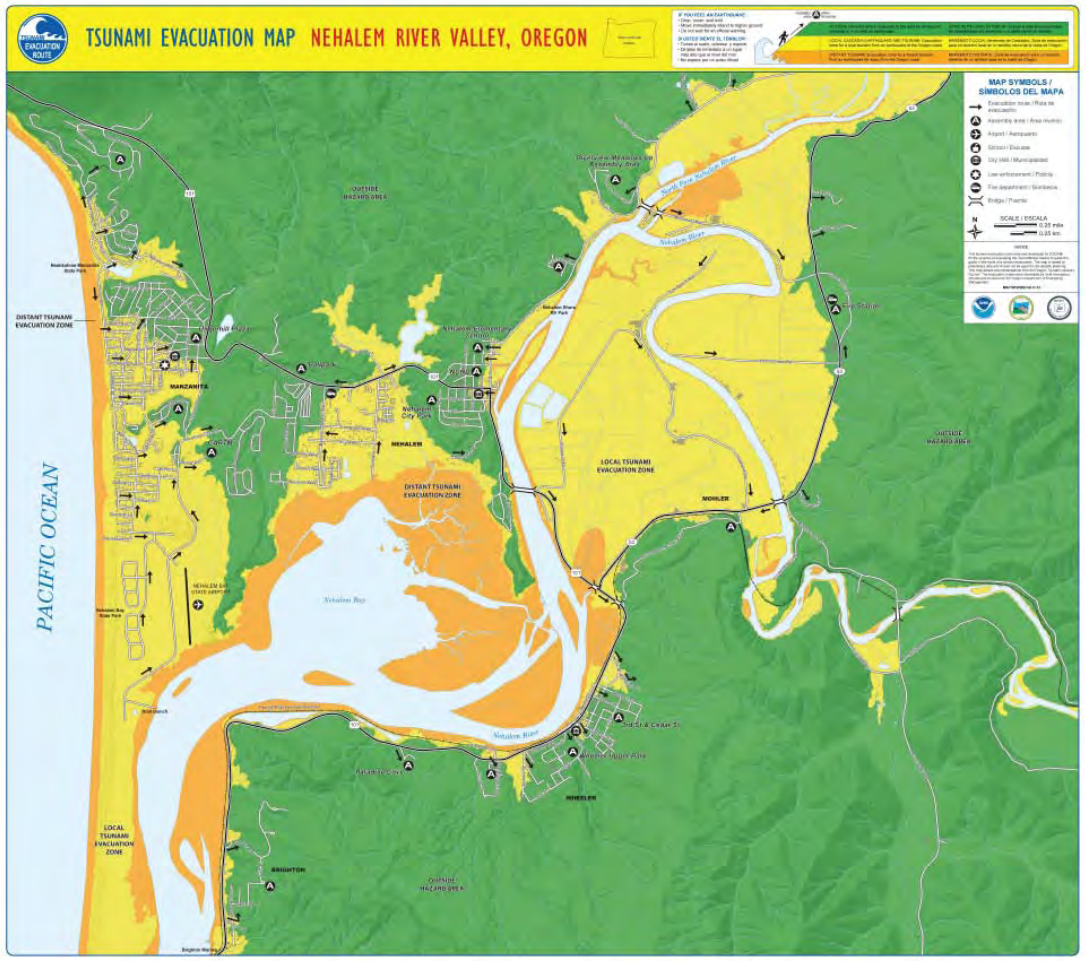
*Building counts shown are based on polygon centroids and are cumulative within the map area.

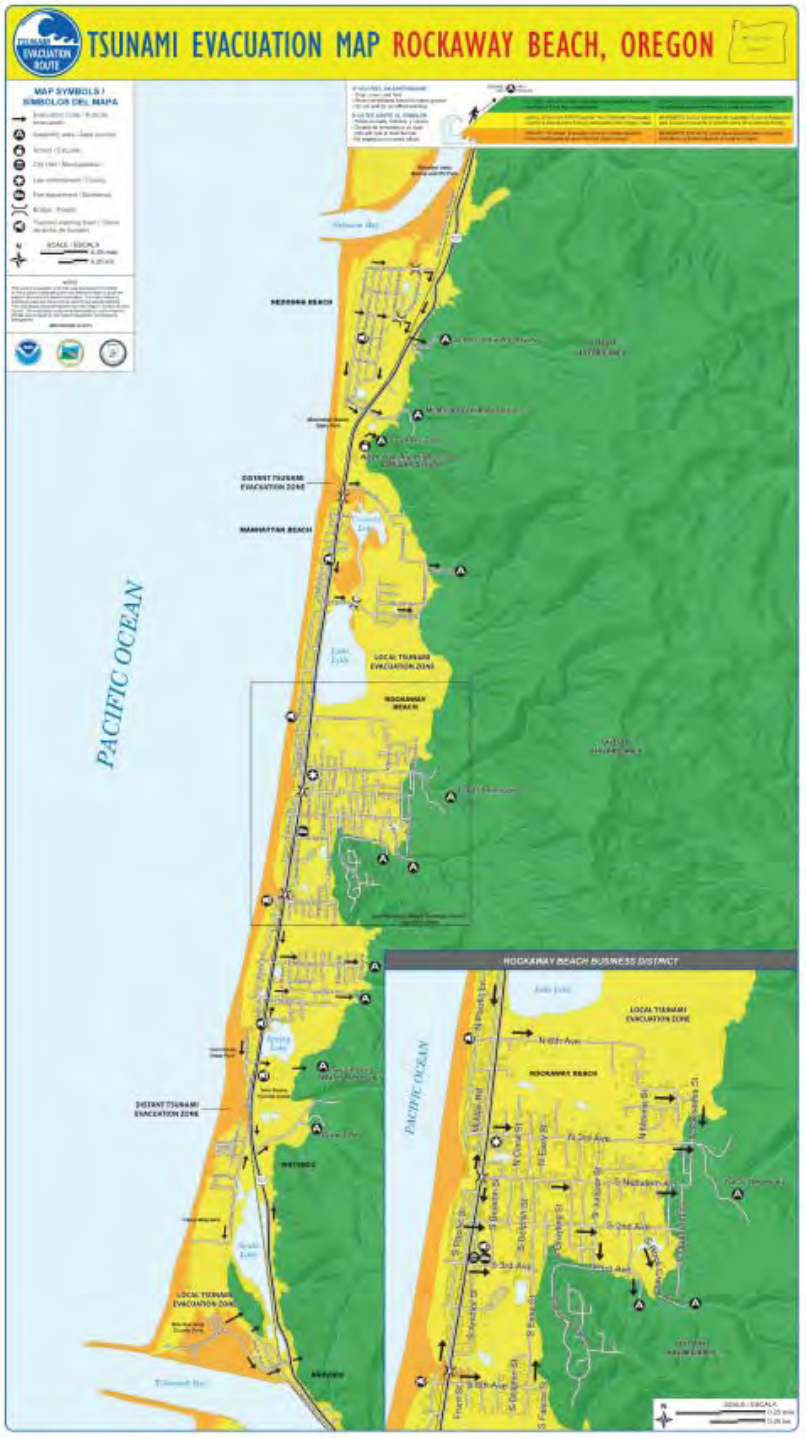


NEW
Evacuation Brochures

Evacuation brochure shows 2 scenarios:

- **Worst-case Local Scenario (XXL)**
- **Worst-case Distant Scenario (Alaska Max)**





Community Determines Evacuation Elements

MAP SYMBOLS / SÍMBOLOS DEL MAPA

- Evacuation route / Ruta de evacuación
- Assembly area / Área reunión
- Hospital / Hospital
- School / Escuela
- City Hall / Municipalidad
- Bridge / Puente
- Law enforcement / Policía
- Fire Department / Bomberos
- Tsunami warning siren / Sirena de aviso de tsunami
- Airport / Aeropuerto
- 35′ Elevation, in feet

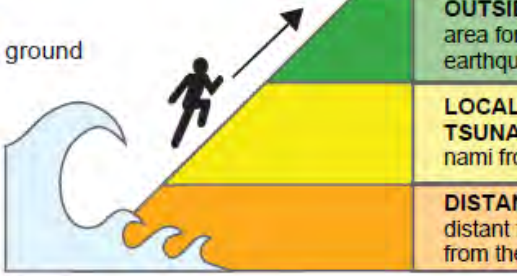
ASSEMBLY AREA (A) ÁREA REUNIÓN

IF YOU FEEL AN EARTHQUAKE:

- Drop, cover, and hold
- Move immediately inland to higher ground
- Do not wait for an official warning

SI USTED SIENTE EL TEMBLOR:

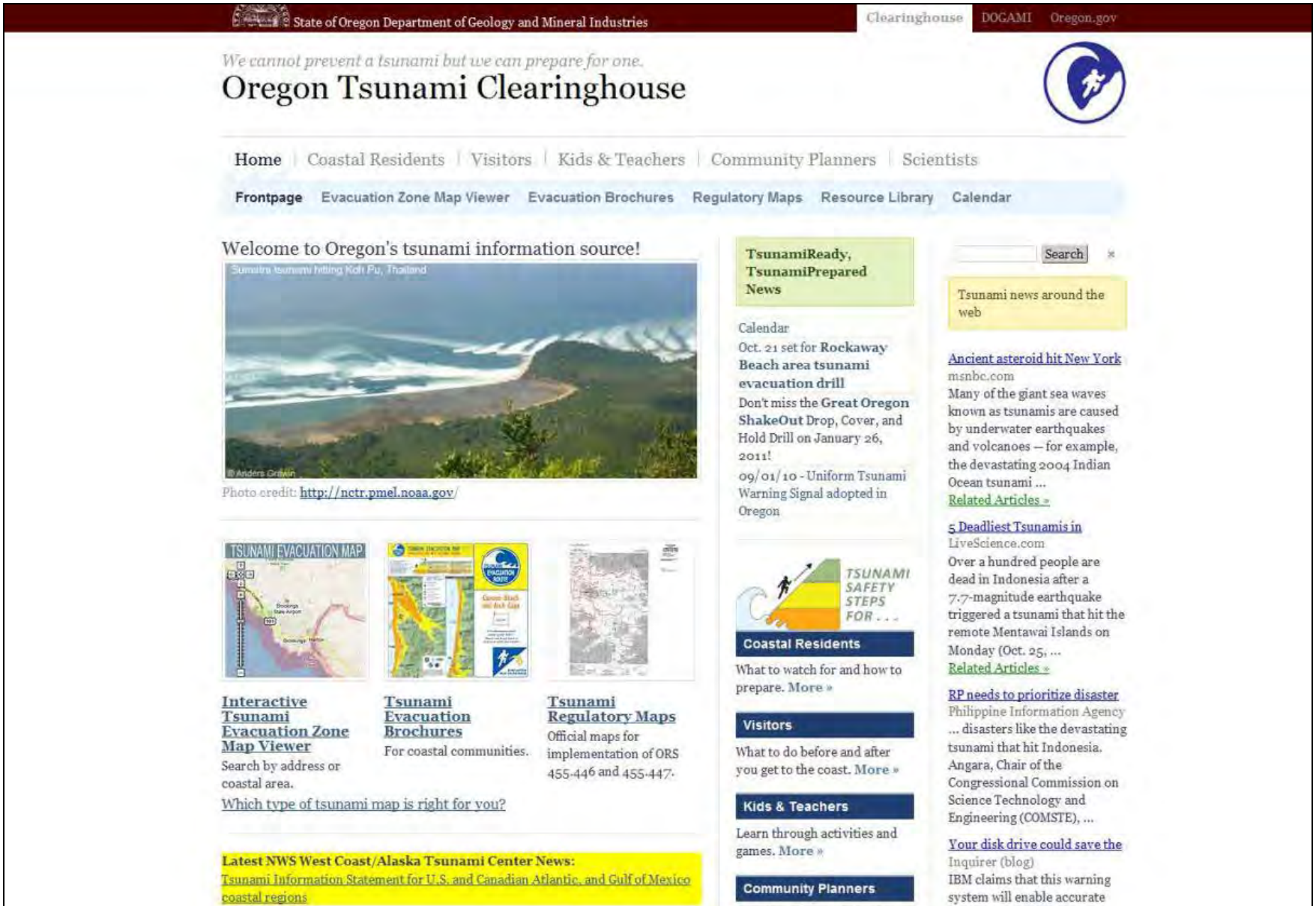
- Tírese al suelo, cúbrase, y espere
- Diríjase de inmediato a un lugar más alto que el nivel del mar
- No espere por un aviso oficial



OUTSIDE HAZARD AREA: Evacuate to this area for all tsunami warnings or if you feel an earthquake.	**ZONA DE PELIGRO EXTERIOR:** Evacue a esta área para todas las advertencias del maremoto o si usted siente un temblor.
LOCAL CASCADIA EARTHQUAKE AND TSUNAMI: Evacuation zone for a local tsunami from an earthquake at the Oregon coast.	**MAREMOTO LOCAL (terremoto de Cascadia):** Zona de evacuación para un tsunami local de un temblor cerca de la costa de Oregon.
DISTANT TSUNAMI: Evacuation zone for a distant tsunami from an earthquake far away from the Oregon coast.	**MAREMOTO DISTANTE:** Zona de evacuación para un tsunami distante de un temblor lejos de la costa de Oregon.

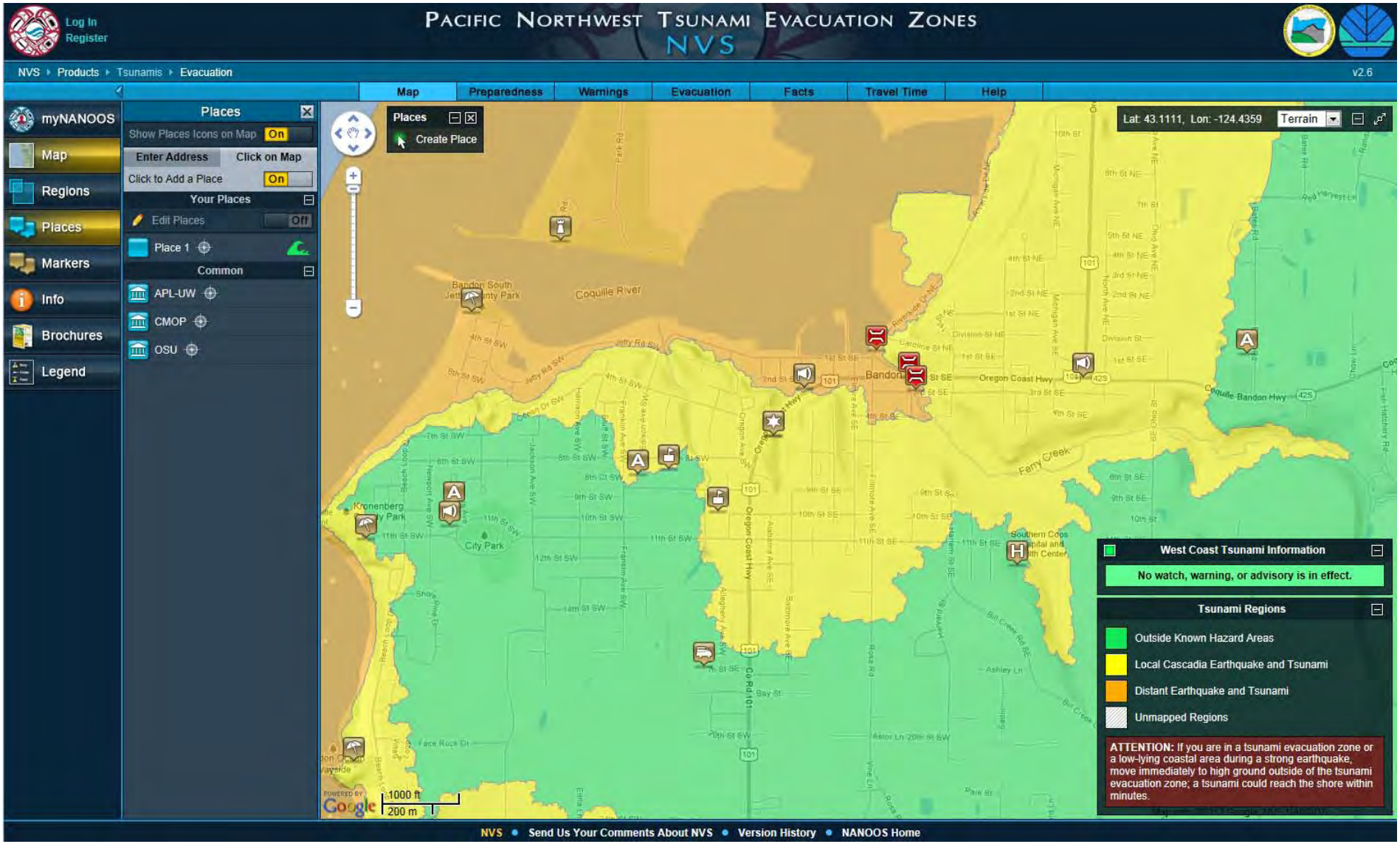
Oregon Tsunami Clearinghouse

www.OregonTsunami.com

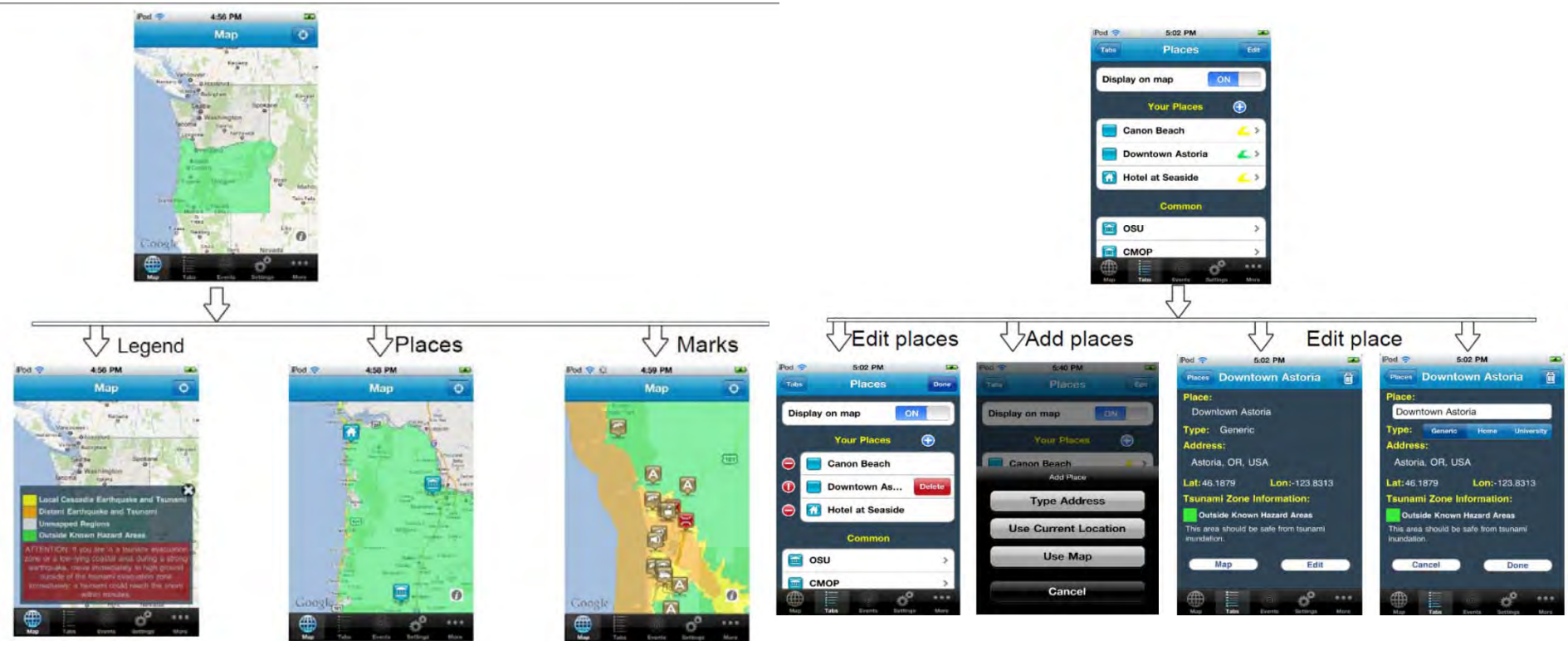


Online Viewer - NANOOS

www.OregonTsunami.org



Web Apps – IPhone & Android



Earthquakes: What to do…

Indoors: Drop, cover, and hold on. Drop to the floor, take cover under a sturdy desk or table, and hold on to it firmly.

In Bed: Hold on and stay there, protecting your head with a pillow.

Outdoors: Move to a clear area if you can safely do so; avoid power lines, trees, signs, buildings, vehicles, and other hazards.

Driving: Pull over to the side of the road, stop, and set the parking brake. Avoid overpasses, bridges, power lines, signs and other hazards. Stay inside the vehicle until the shaking is over.

At the beach: Drop, cover and hold on until the shaking stops. Estimate how long the shaking lasts. If severe shaking lasts 20 seconds or more, immediately evacuate to high ground as a tsunami might have been generated by the earthquake.

In a high-rise building: Drop, cover, and hold on. Avoid windows and other hazards. Do not use elevators.

Tsunamis: What to do…

- **Get** Involved (Map Your Neighborhood, CERT)
- **Prepare** Emergency "Go-kit" to ***Carry Along***
- **Know** Your Route from Evacuation Brochures
  - (www.oregontsunami.org)
- After shaking stops, **Evacuate Immediately** to High Ground/Assembly Area
- **Stay** until the "All Clear" is announced