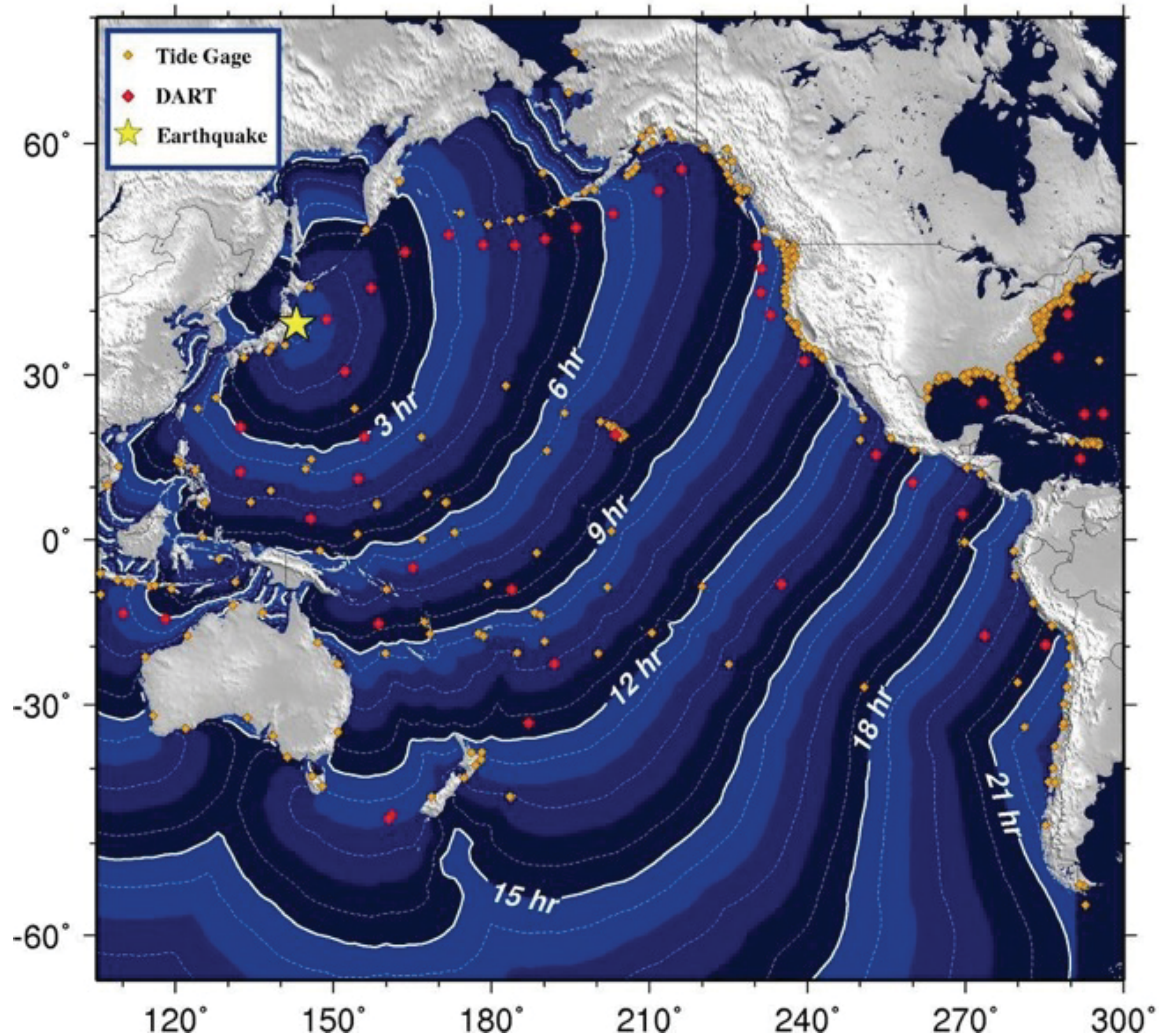
Pacific Ocean Tsunami Generated by Japan Earthquake

Near the earthquake, there were only ~20 minutes to evacuate. A “local tsunami” for Japan.

Travel times are well known for tsunamis crossing the Pacific Ocean.

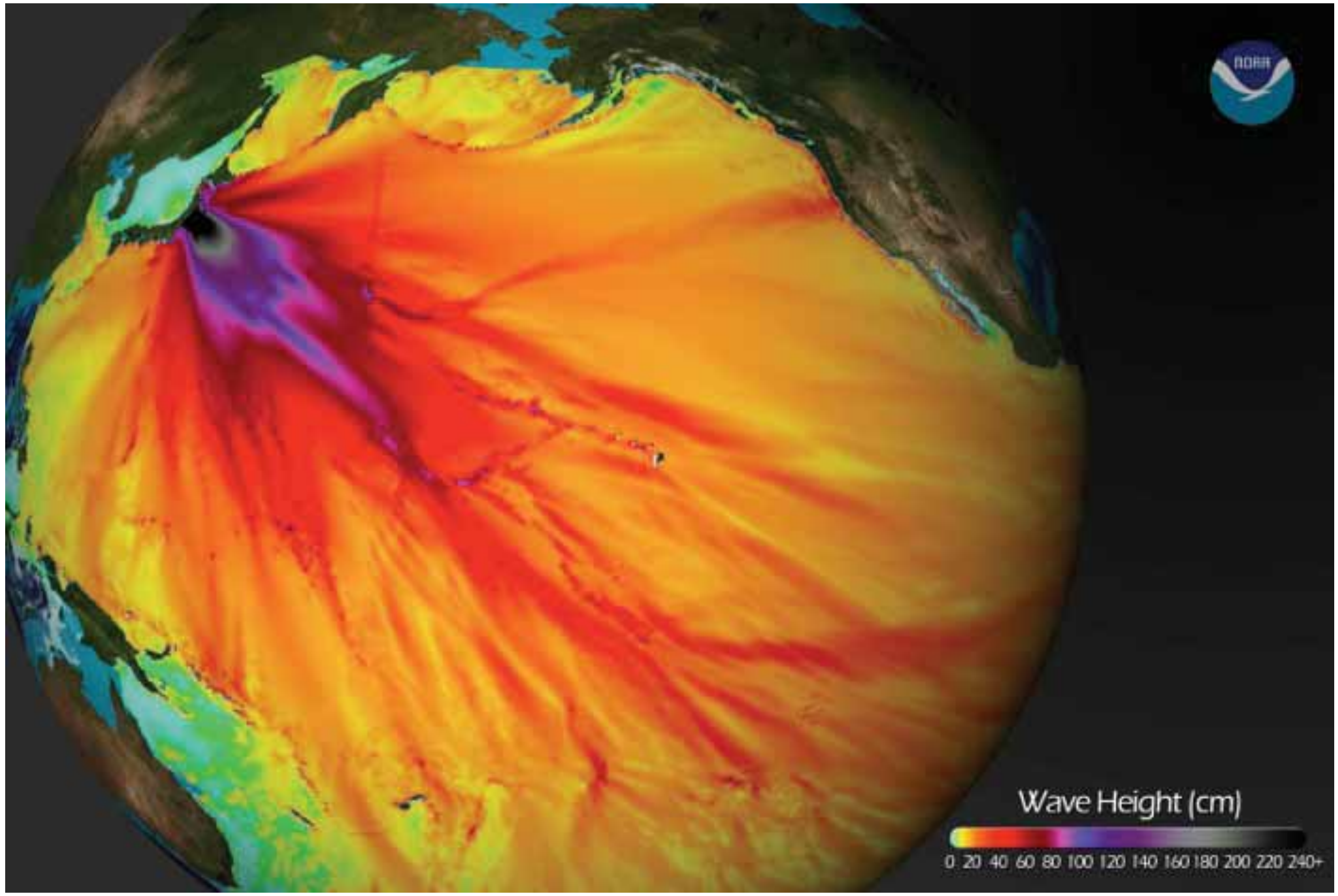
At distant locations, there were hours of advance warning. A “distant tsunami” for Oregon coast.



Pacific Ocean Tsunami Generated by Japan Earthquake

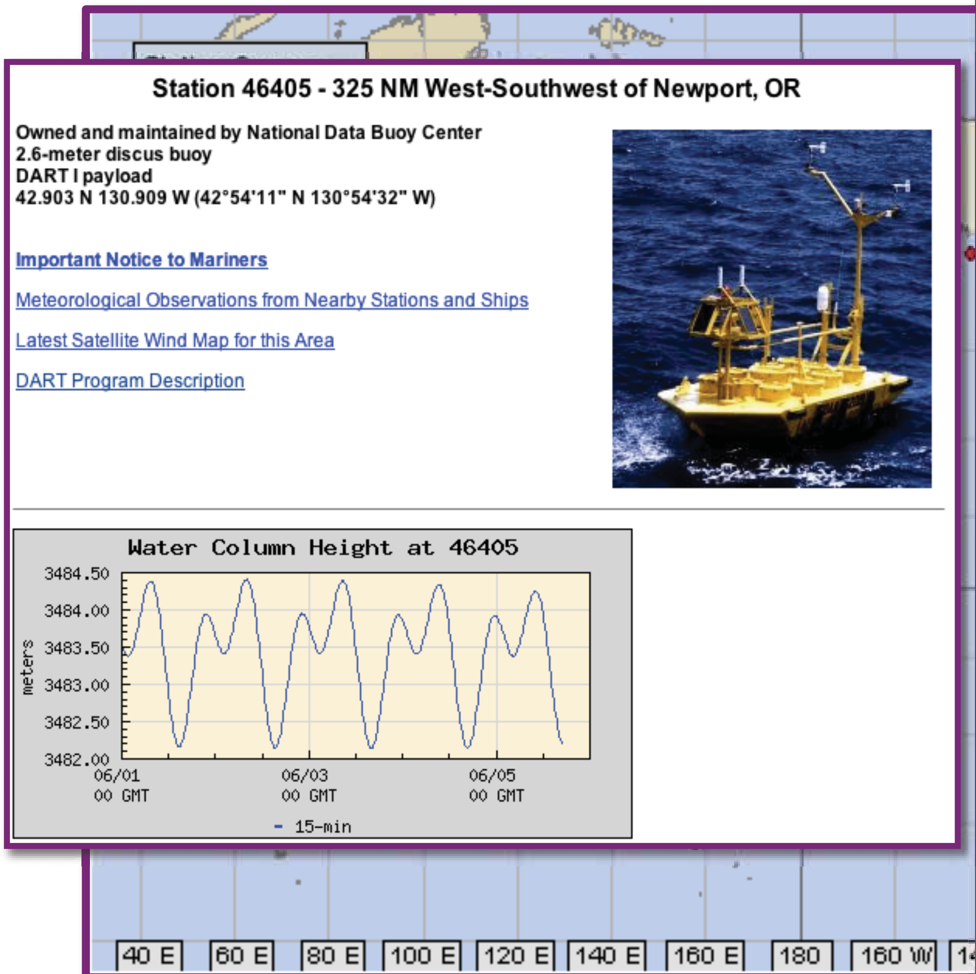
Tsunami height model shows forecast wave height (in cm).

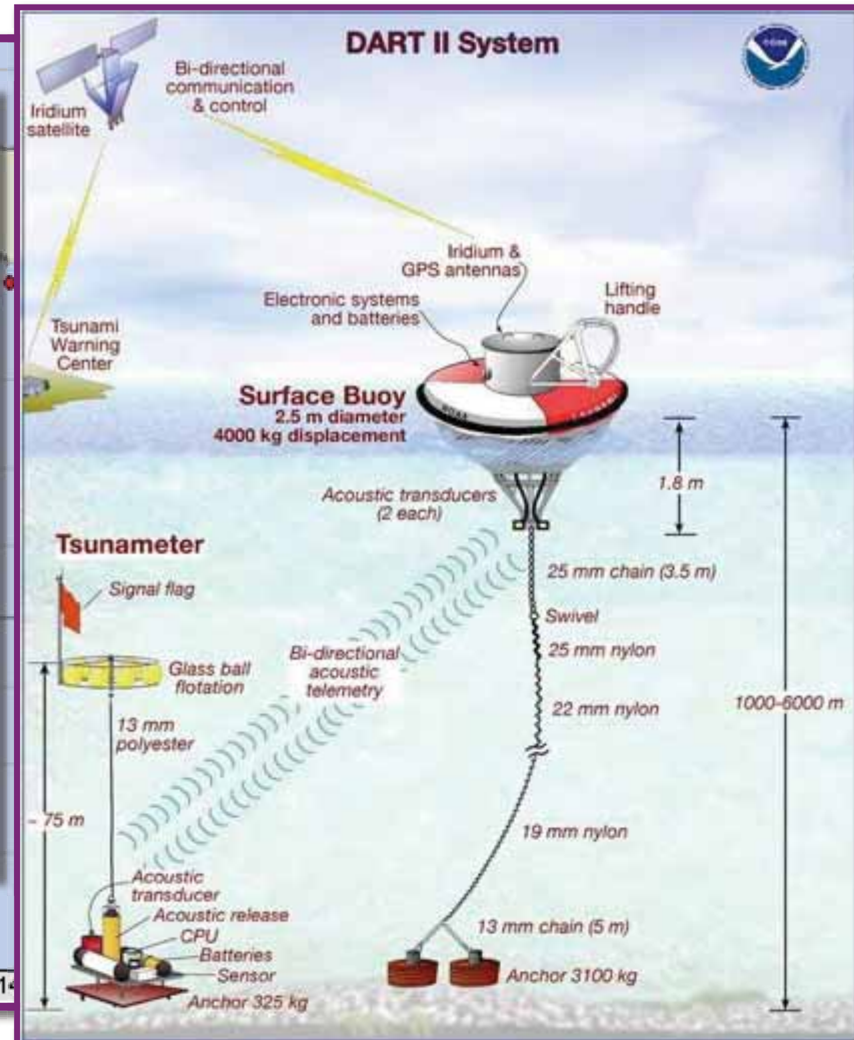
Ocean floor bathymetry affects the wave height because of reflections and refractions from seafloor features and islands.



Tsunami evacuations were ordered for Hawaii, Oregon, and northern California but not Washington. Wave heights were accurately predicted.

Deep-ocean Assessment and Reporting of Tsunami (DART)



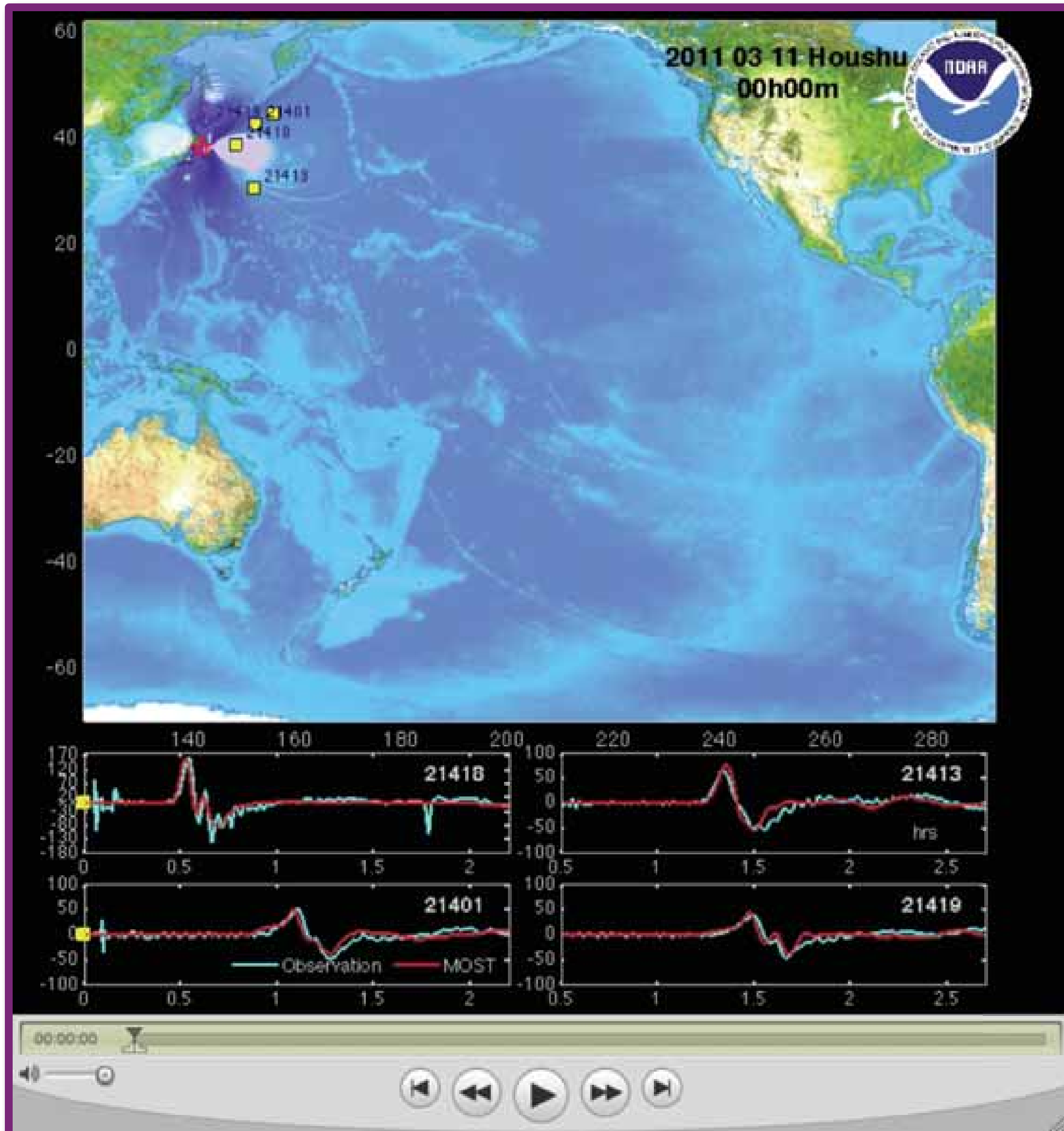


Pacific Ocean Tsunami Generated by Japan Earthquake

Peak-to-trough wave height was nearly 2 m at nearest DART buoy in 4000 m water depth!

Travel time to Oregon and Washington coast was about 9 hours.

Largest waves affected OR and CA MANY hours after first waves arrived.

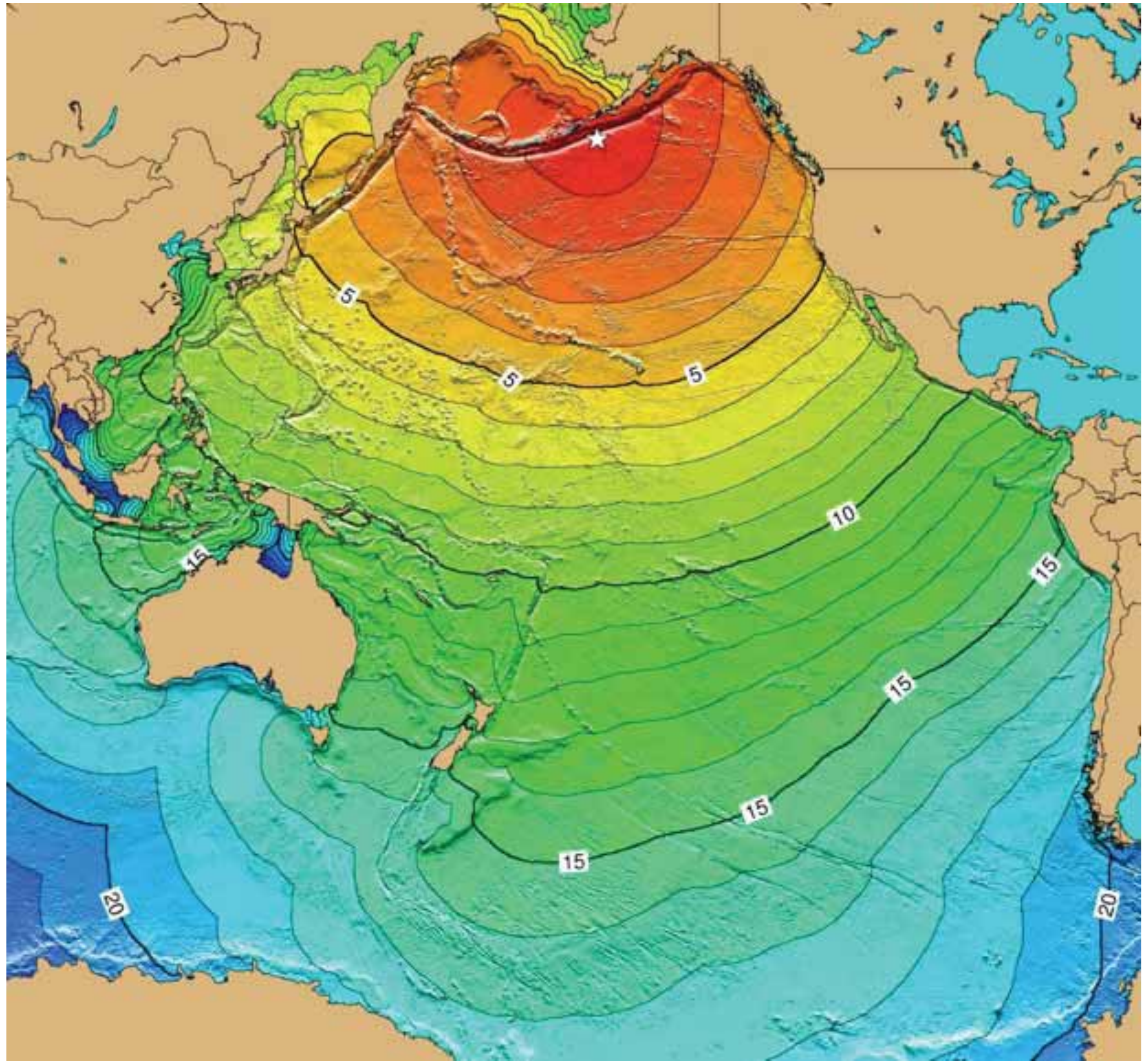


Pacific Ocean Tsunami Generated by Alaska Earthquake

About four hours travel time to Oregon Coast.

Tsunami from 1964 Alaska EQ killed 4 children on Beverly Beach. The largest of 28 distant tsunamis to affect Oregon coast since 1854.

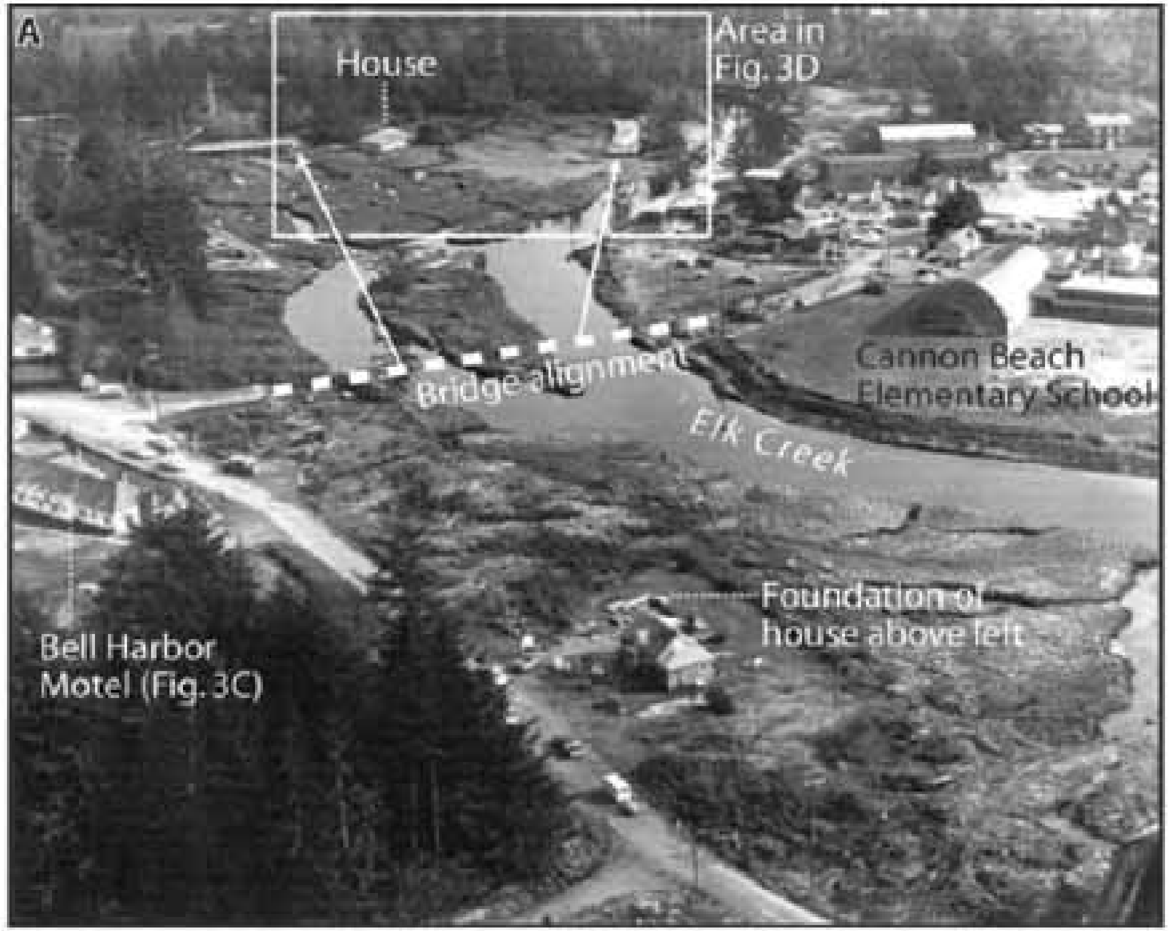
Significant damage in Seaside and Cannon Beach. Major destruction and 13 deaths in Crescent City, CA.



Damage in Cannon Beach from 1964 Alaska Tsunami

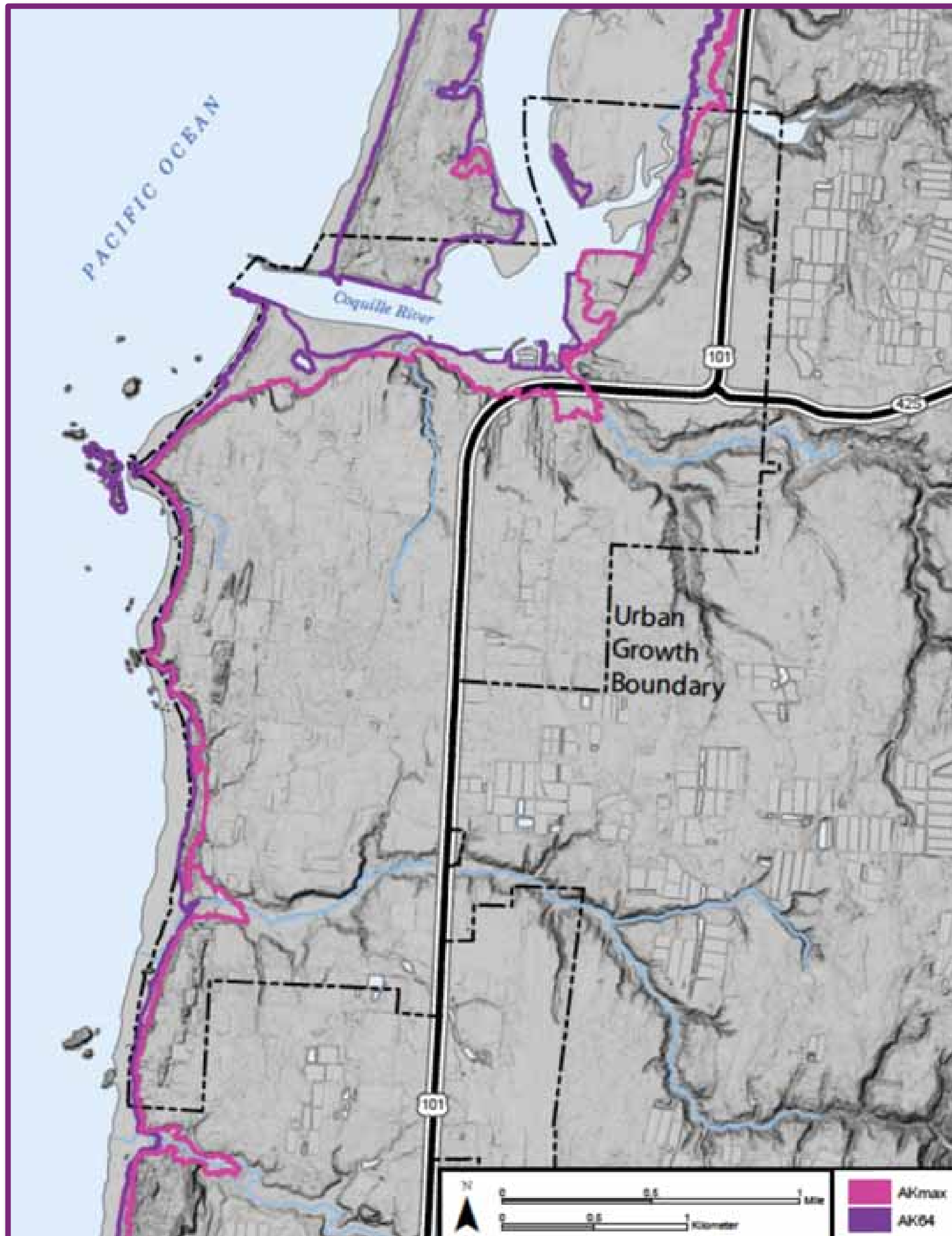
Bridge over Elk Creek (now Ecola Creek) destroyed and displaced 300 m upstream.

House torn from foundation and displaced 400 m upstream.



From Priest and others, DOGAMI Special Paper 41, 2009.

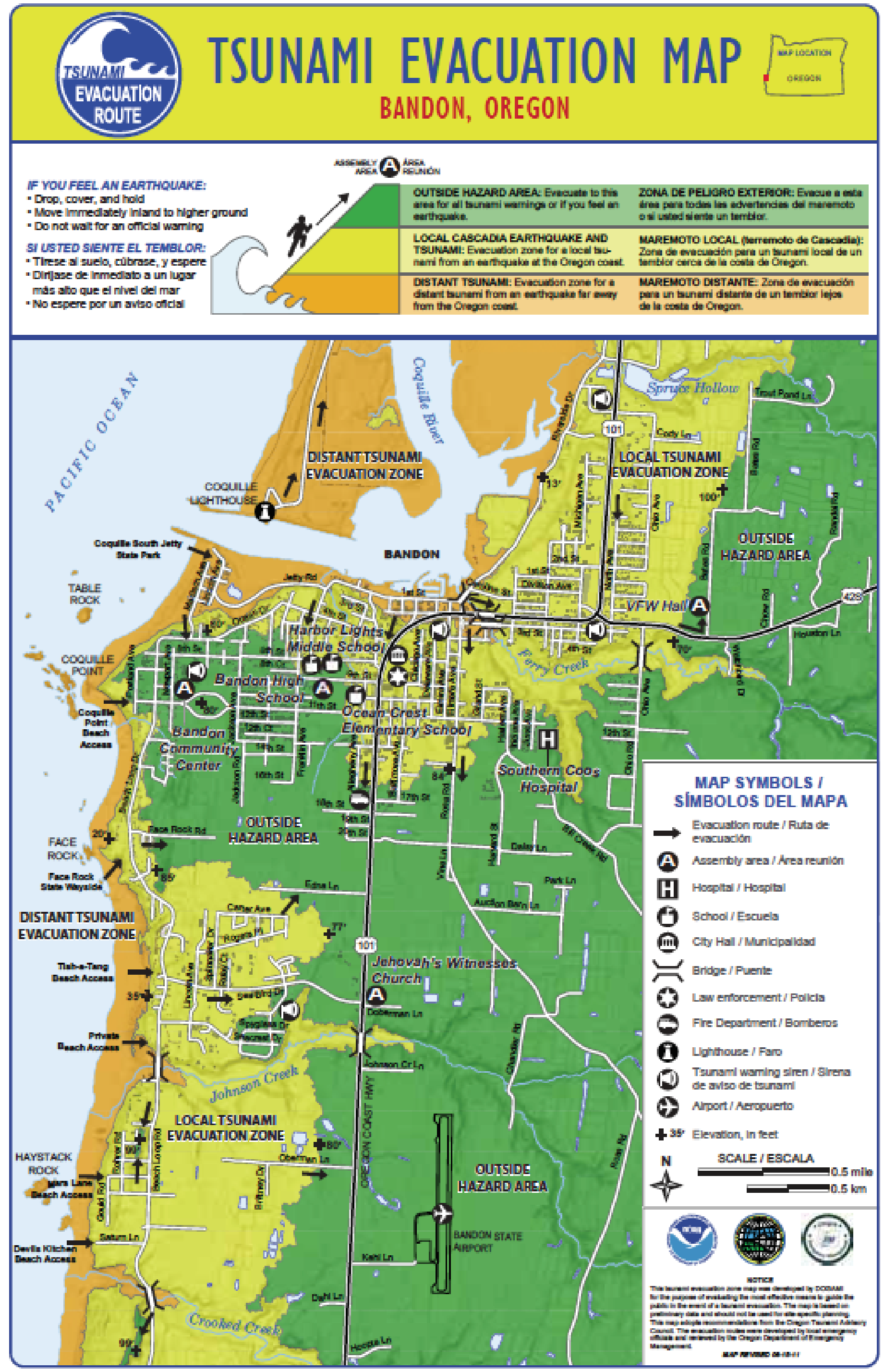
Distant Tsunami Inundation Map for Bandon, Oregon



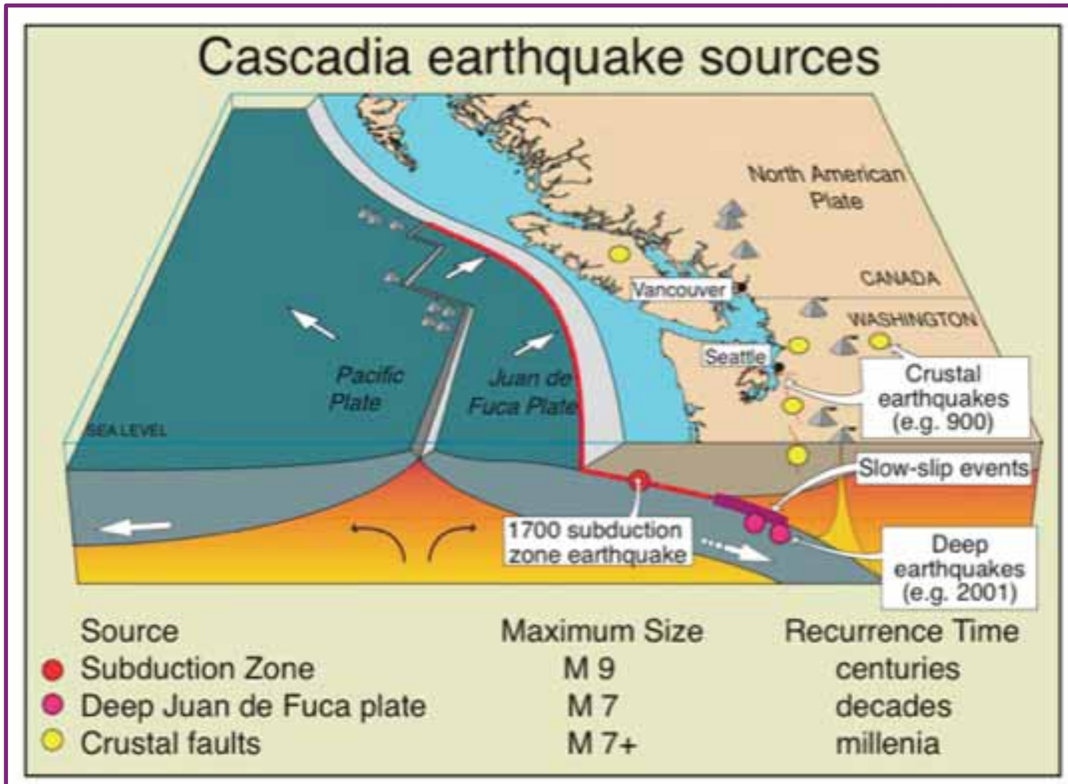
Tsunami Evacuation Map for Bandon, Oregon

Distant tsunami evacuation zone determined from maximum Alaska tsunami.

Local Tsunami Evacuation Zone determined from maximum Cascadia tsunami.



Past Great Cascadia Earthquakes and Tsunamis



Juan de Fuca subducts beneath Pacific Northwest portion of North American Plate at Cascadia subduction zone.

Last great Cascadia earthquake occurred on January 26, 1700 at about 9:00 PM local time.

Analogous to Sumatra 2004, Chile 2010, and Tohoku, Japan 2011 great earthquakes.

Some Coast Areas Now Below Sea Level
Yuriage

Before

After

- Some areas that were above sea level on march 10 dropped below sea level on March 11, 2011.
- This also happened along the Washington - Oregon coast during the 1700 AD great Cascadia earthquake.

Drowned Forests of Coastal Oregon and Washington

Ghost forest on Copalis River

Brian Atwater, USGS Seattle

Coastal "drowned forests" record the history of slow uplift between and sudden subsidence during great Cascadia earthquakes.

Drowned Forests of Coastal Oregon and Washington

David Yamaguchi

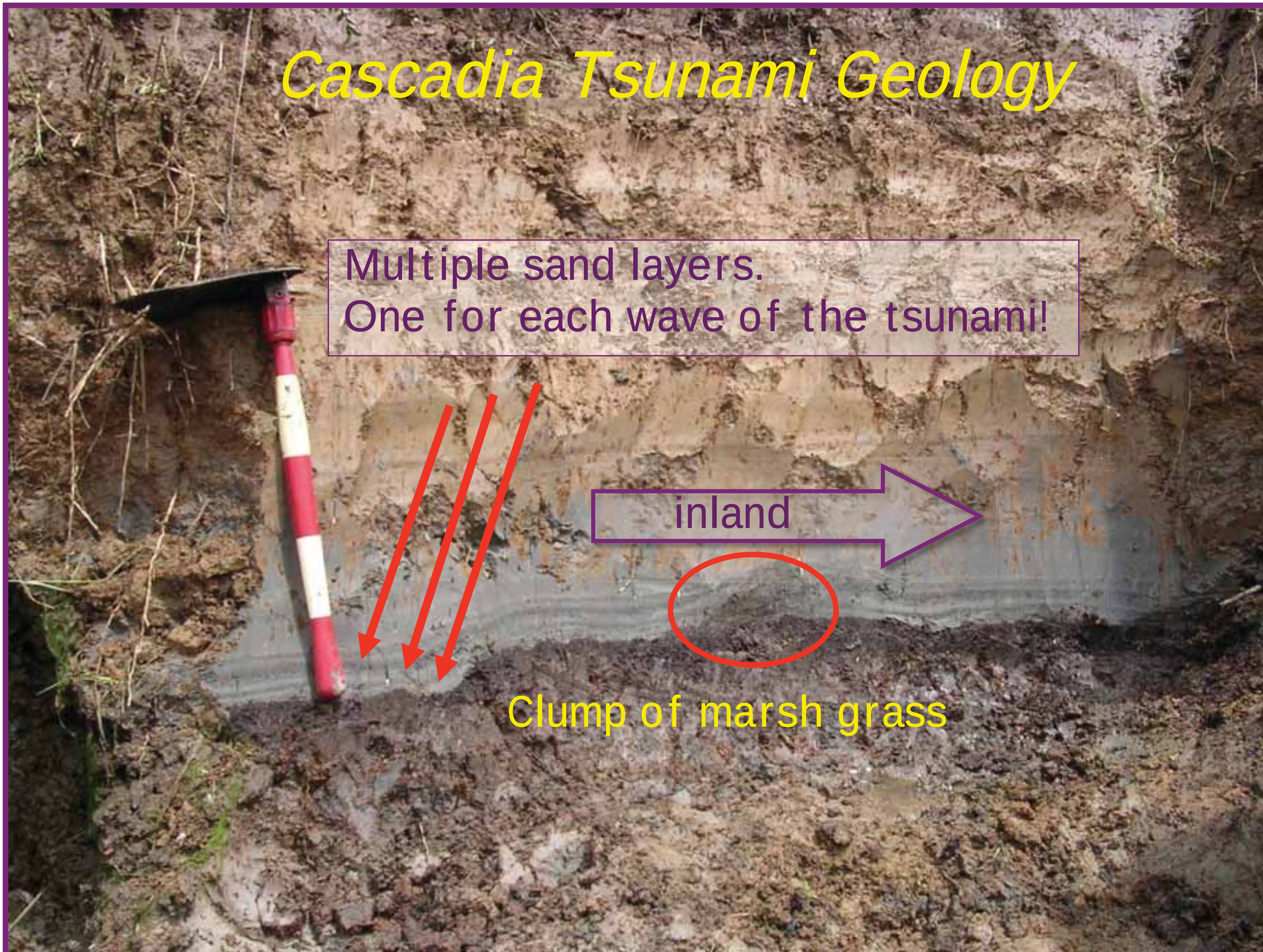
Trees in “drowned forests” near shore died when the ground dropped and seawater killed the trees. Compare rings from victim trees with rings from witness trees on higher ground.

Result: Trees died between fall 1699 and spring 1700.

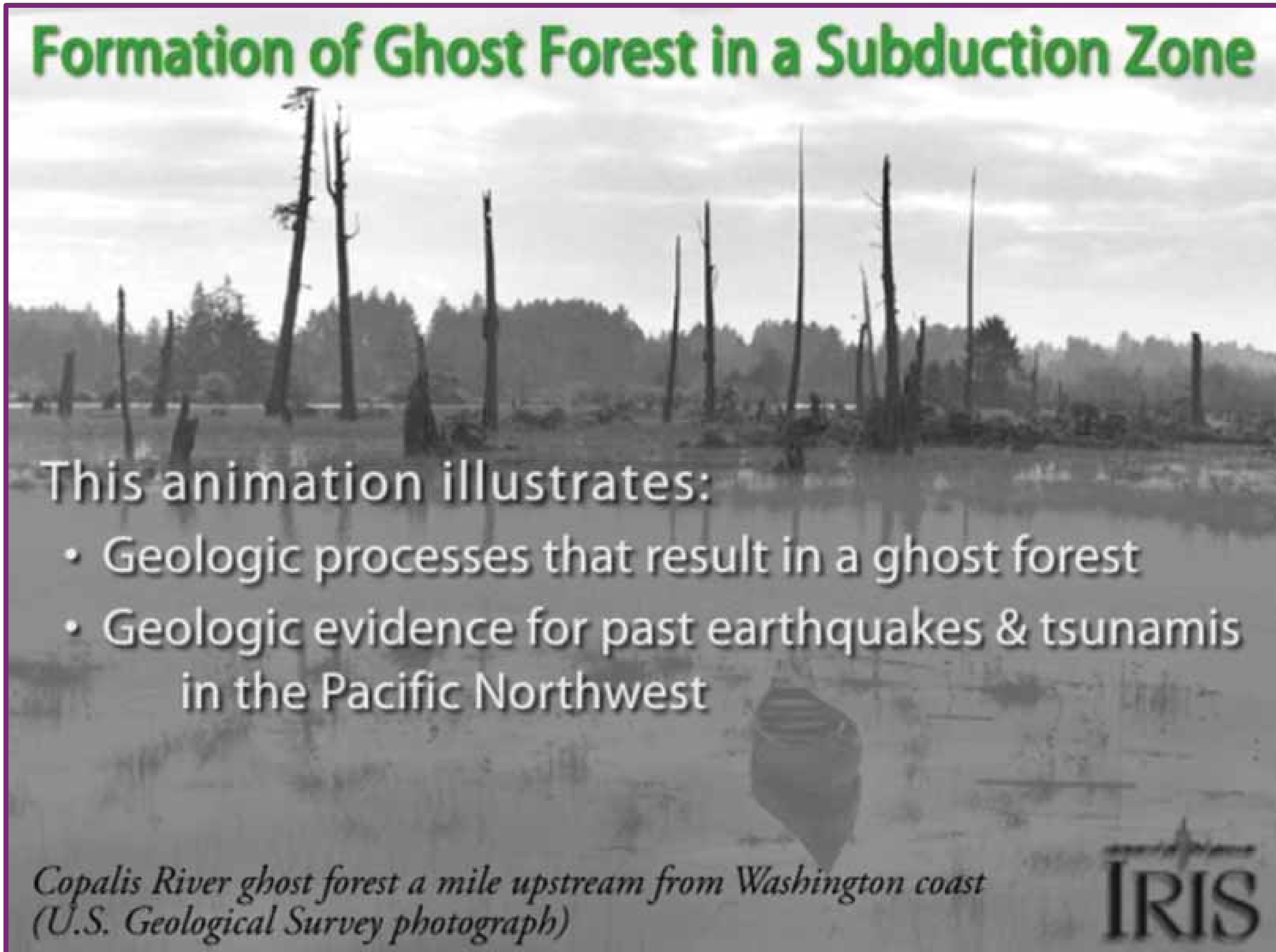
Three-Layer Cake of Cascadia Tsunami Geology

Cupcake Geology

Organic-rich forest soil covered by tsunami sand then intertidal mud and clay on top.


Cascadia Tsunami Geology
Multiple sand layers.
One for each wave of the tsunami!
inland
Clump of marsh grass

Making a Ghost Forest



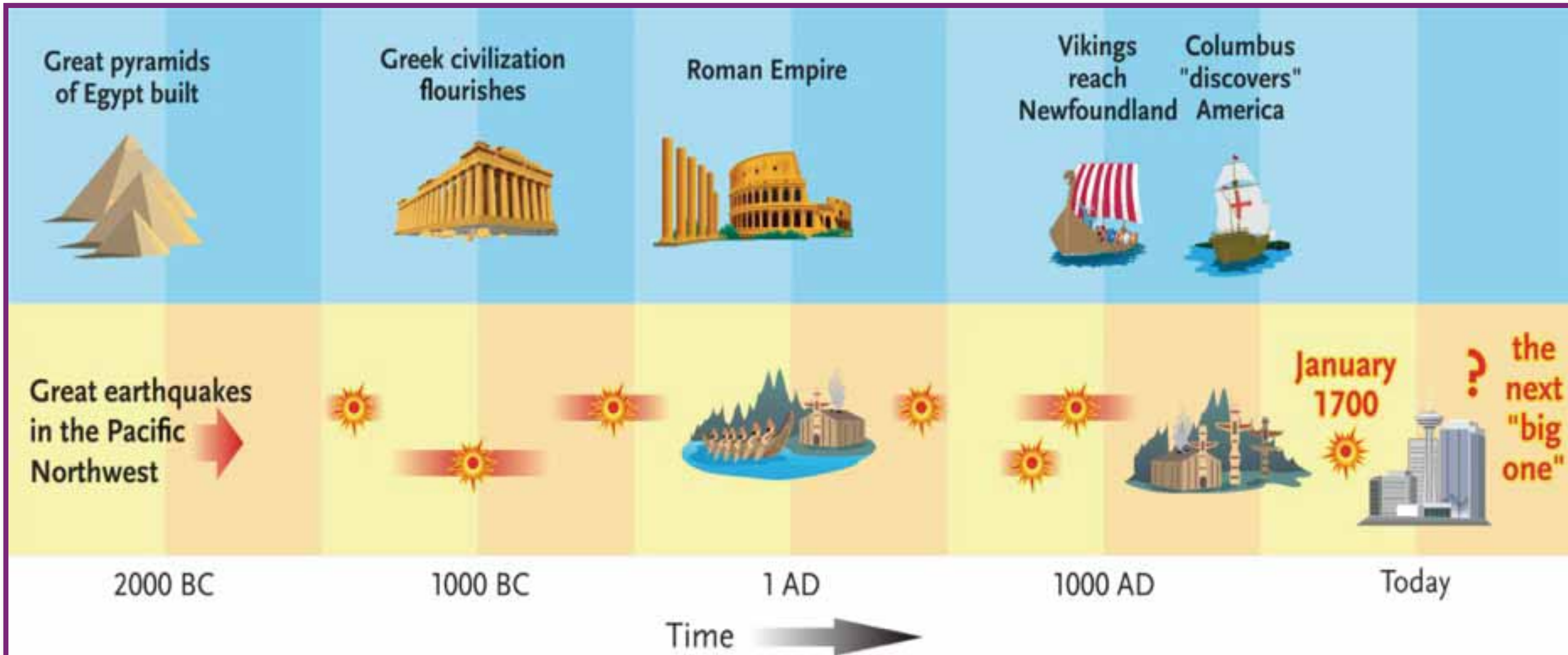
Buried Forest Soils

1700 AD

860(?) AD

Niawiakum River, east of Willapa Bay, WA.

Recent Great Cascadia Earthquakes



Average time between earthquakes = Recurrence time.

Recurrence time for Great Cascadia EQs = 500 years.

We are at 313 years and counting.

Cascadia Tsunami Geology Storyline

Great earthquake January 26, 1700 @ 9 PM

Ghost forests, buried soils, diatoms, tsunami sand sheets, liquefaction, turbidites, Native American oral history, and written Japanese history.

Turbidites in Marine Sediment Cores

Sediment deposited on continental shelf can surge down submarine canyons in turbidity currents. The resulting "turbidite" layer has coarse sand on bottom and fine clay on top.

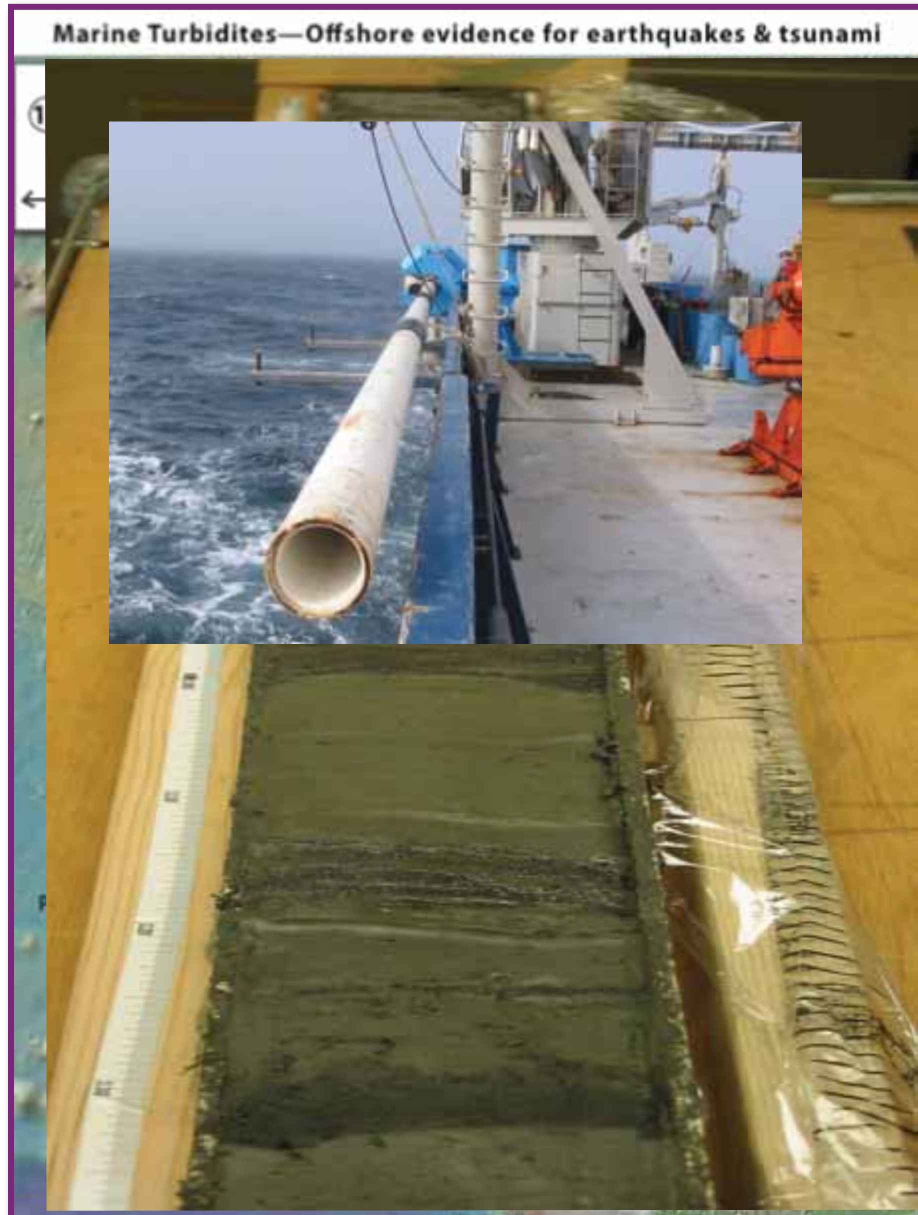
Turbidites in Marine Sediment Cores

Chris Goldfinger (OSU).

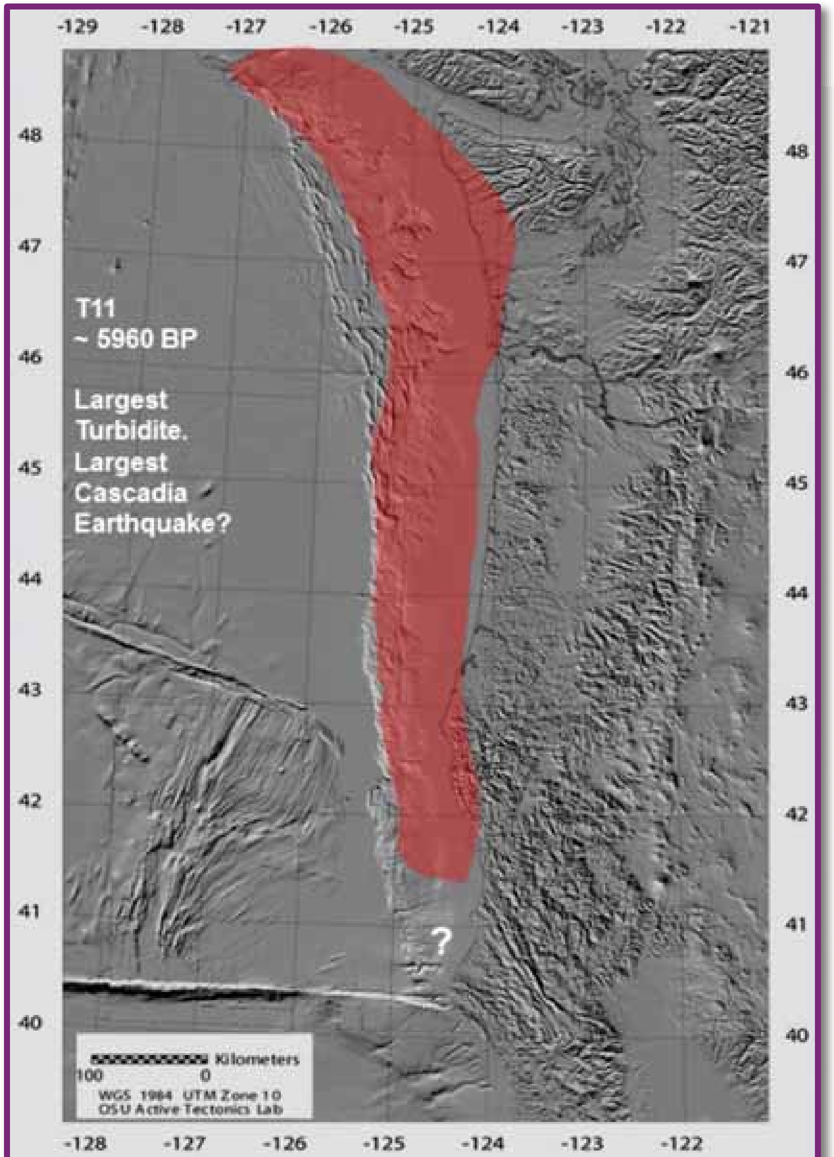
Shaking by great Cascadia earthquakes caused turbidity currents.

Ages of many seafloor turbidites match from offshore northern CA to BC.

Requires great earthquakes that ruptured entire or large segments of the plate boundary.



Turbidites: The Movie



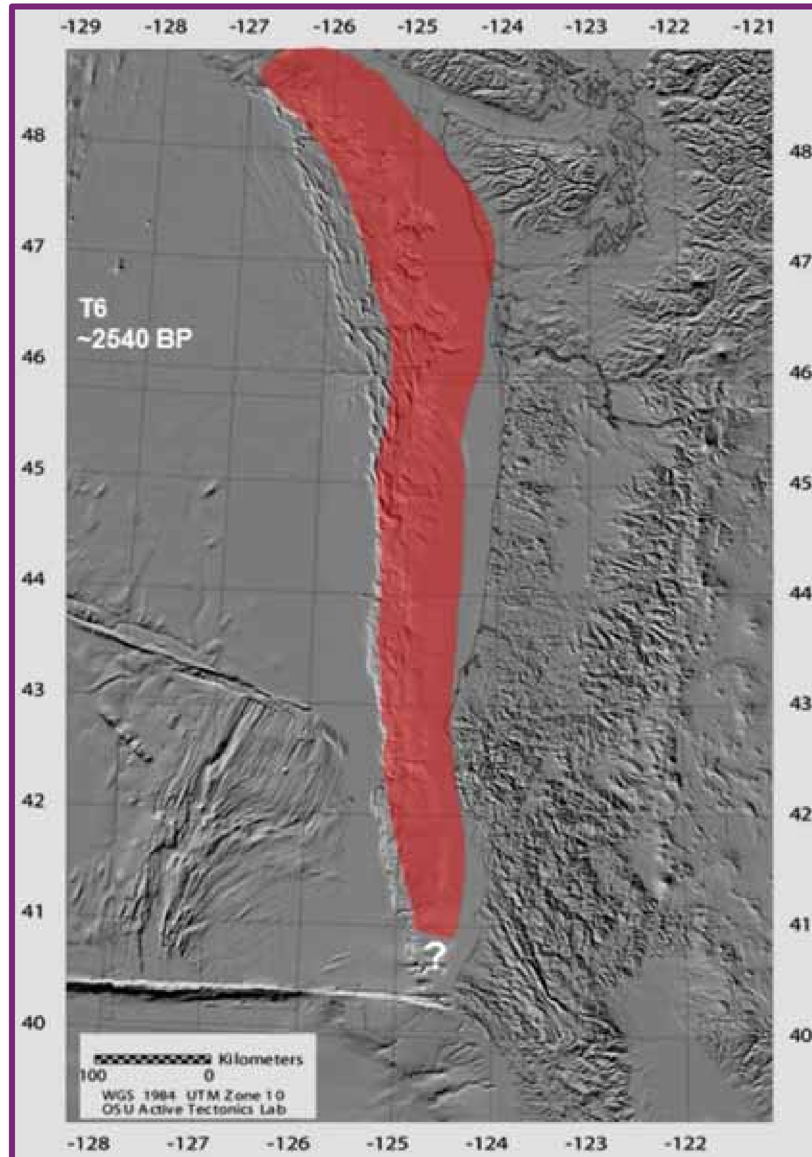
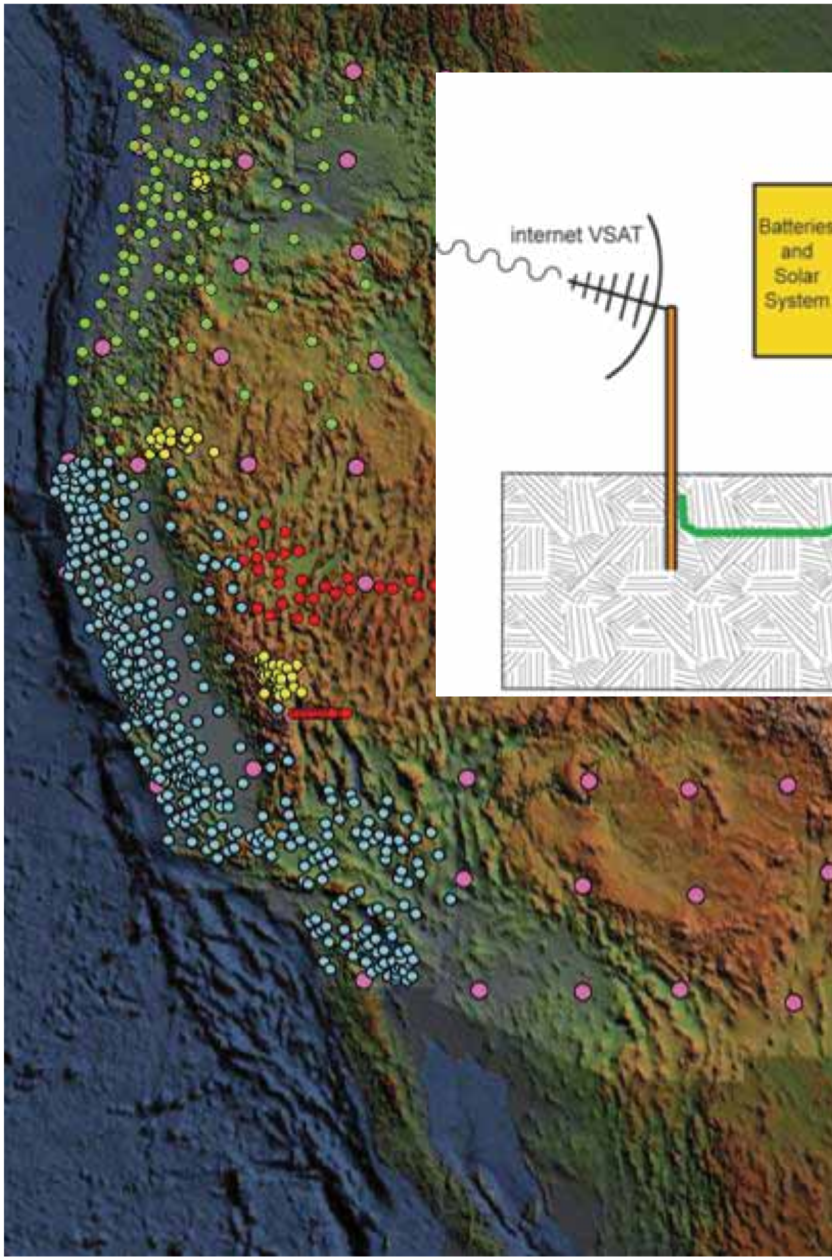
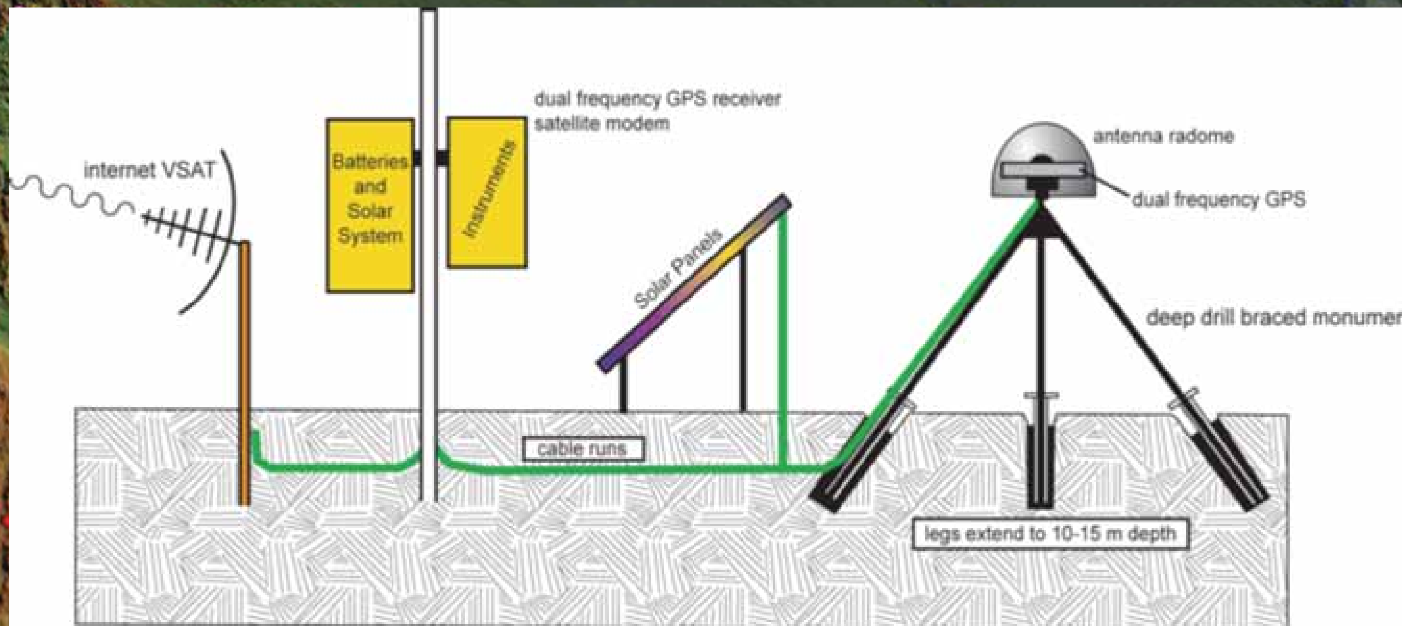


Plate Boundary Observatory (PBO)

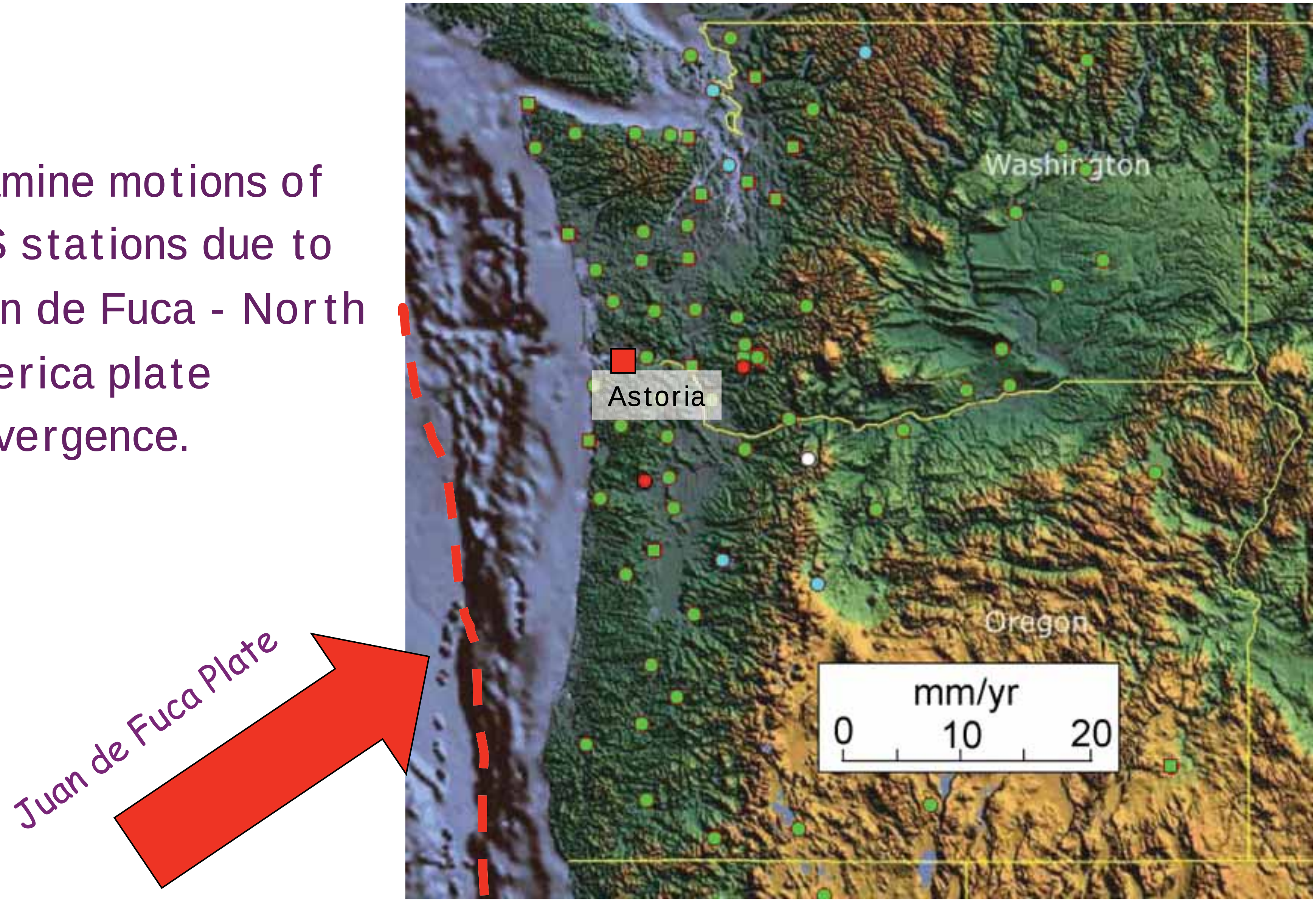




-1100 permanent Global Positioning System (GPS) stations
-78 Borehole Seismometers
-74 Borehole Strainmeters (BSM)
-26 Tiltmeters
-6 Laser Strainmeters (LSM)
Measure the broad temporal and spatial spectrum of plate boundary deformation

Cascadia Locked and Loading

Examine motions of GPS stations due to Juan de Fuca - North America plate convergence.



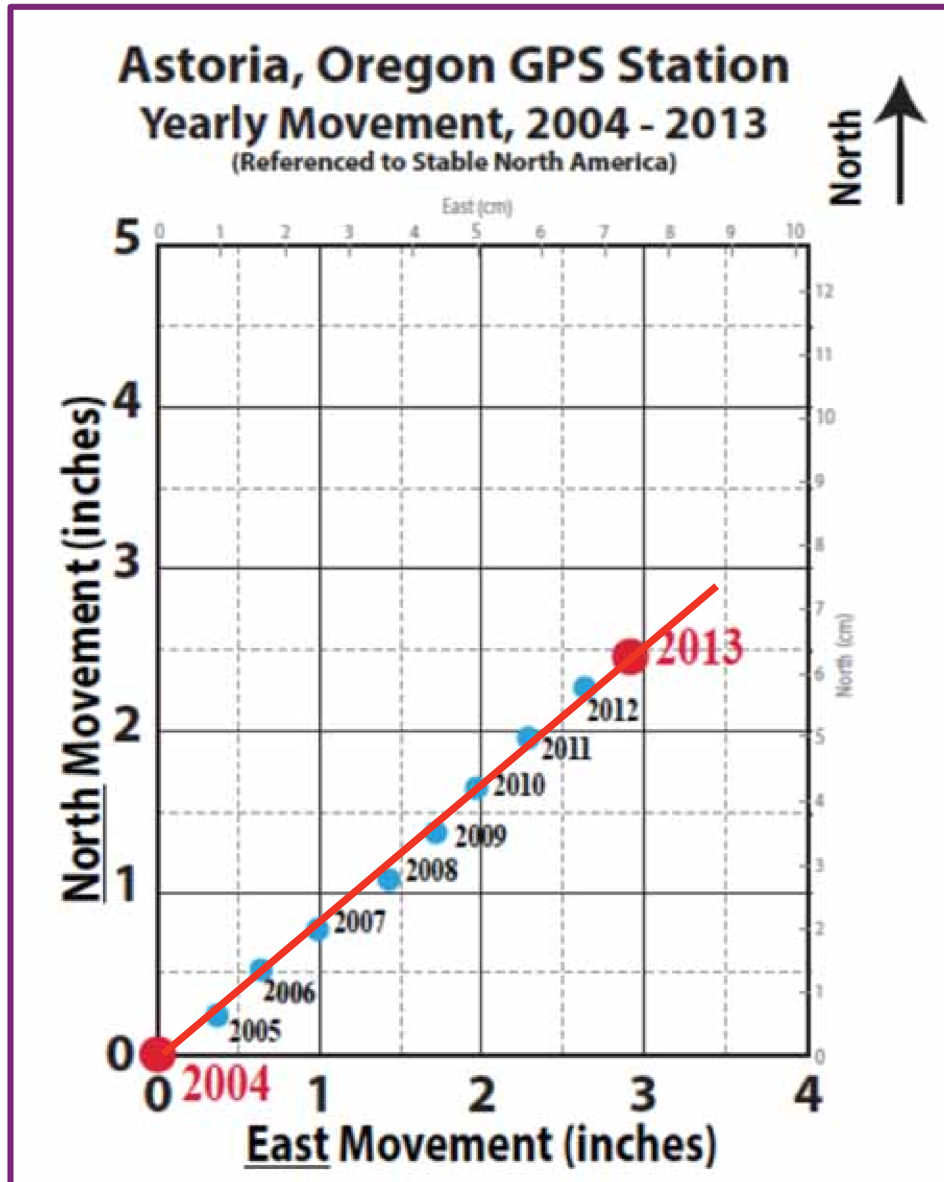
Astoria, OR GPS Observations

Northward motion
= 0.29 inch/yr

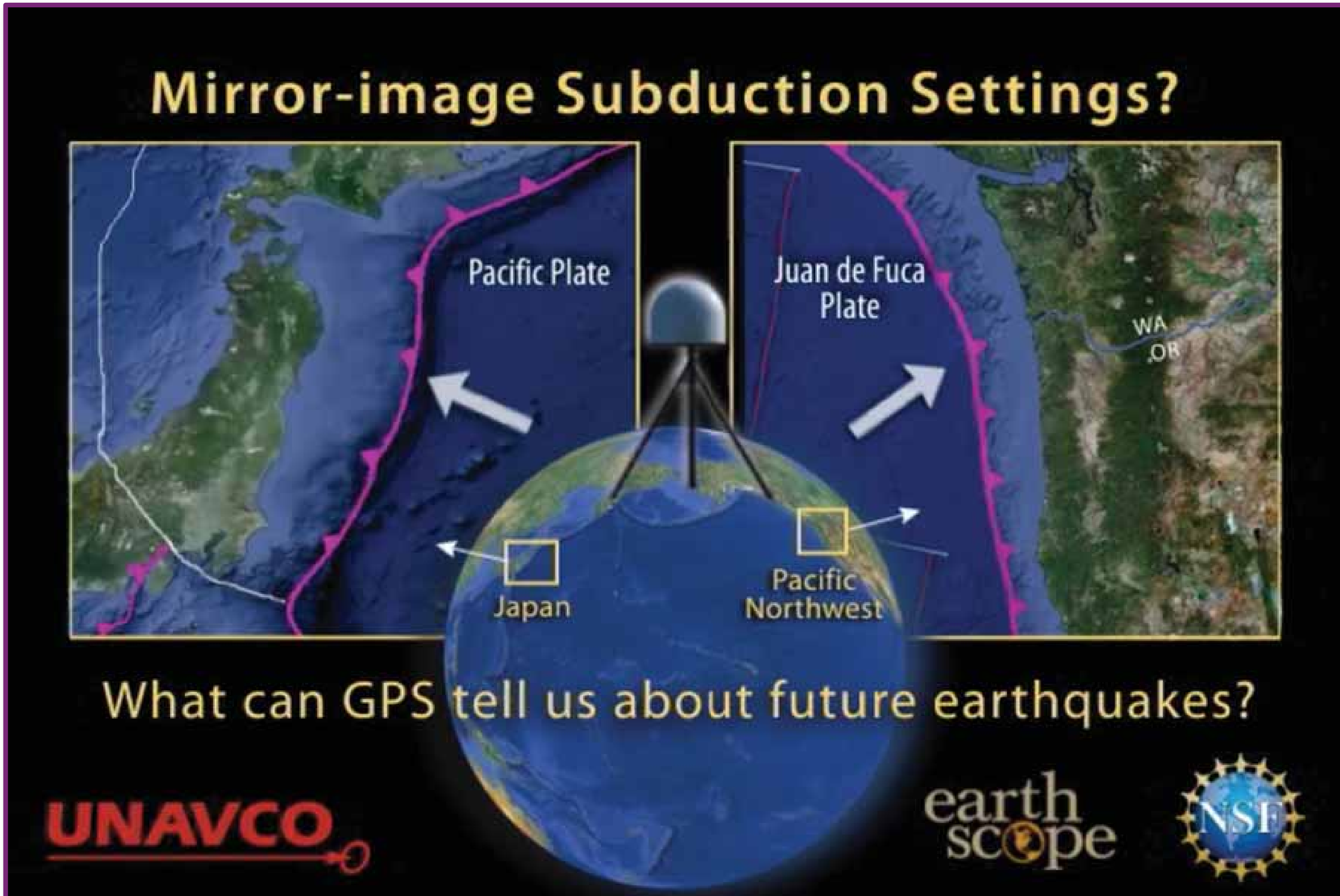
Eastward motion
= 0.33 inch/yr

Total motion
= 0.44 inch/yr

Total motion since 1700 AD
= 11.5 feet



Cascadia GPS Animation



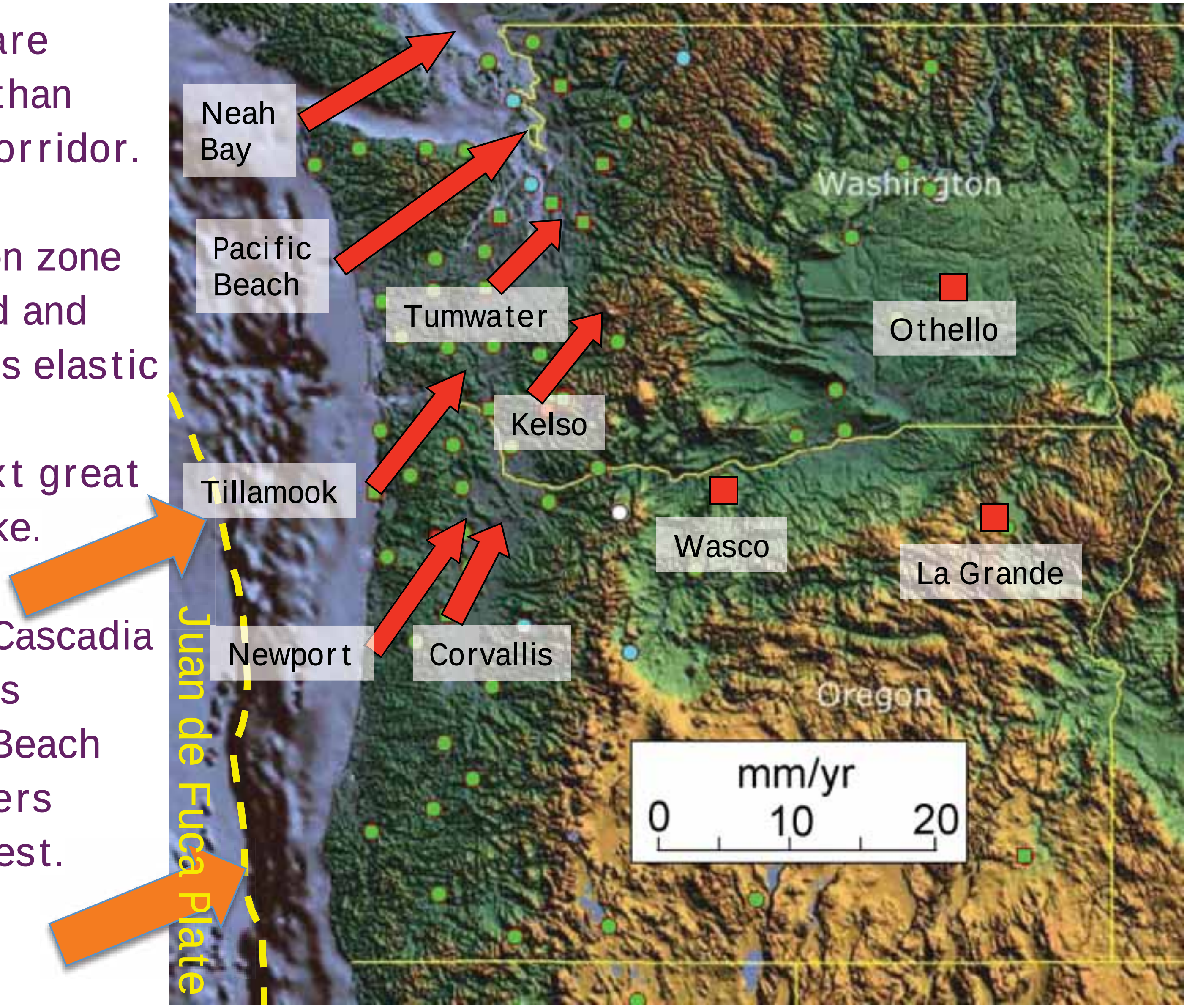
Cascadia Locked and Loading

GPS Gum Drop

Stations on coast are moving NE faster than stations in urban corridor.

Cascadia subduction zone boundary is “locked and loading” as it stores elastic energy that will be released in the next great Cascadia earthquake.

If the next great Cascadia earthquake happens tomorrow, Pacific Beach will jump 5.35 meters (17.5 feet) southwest.



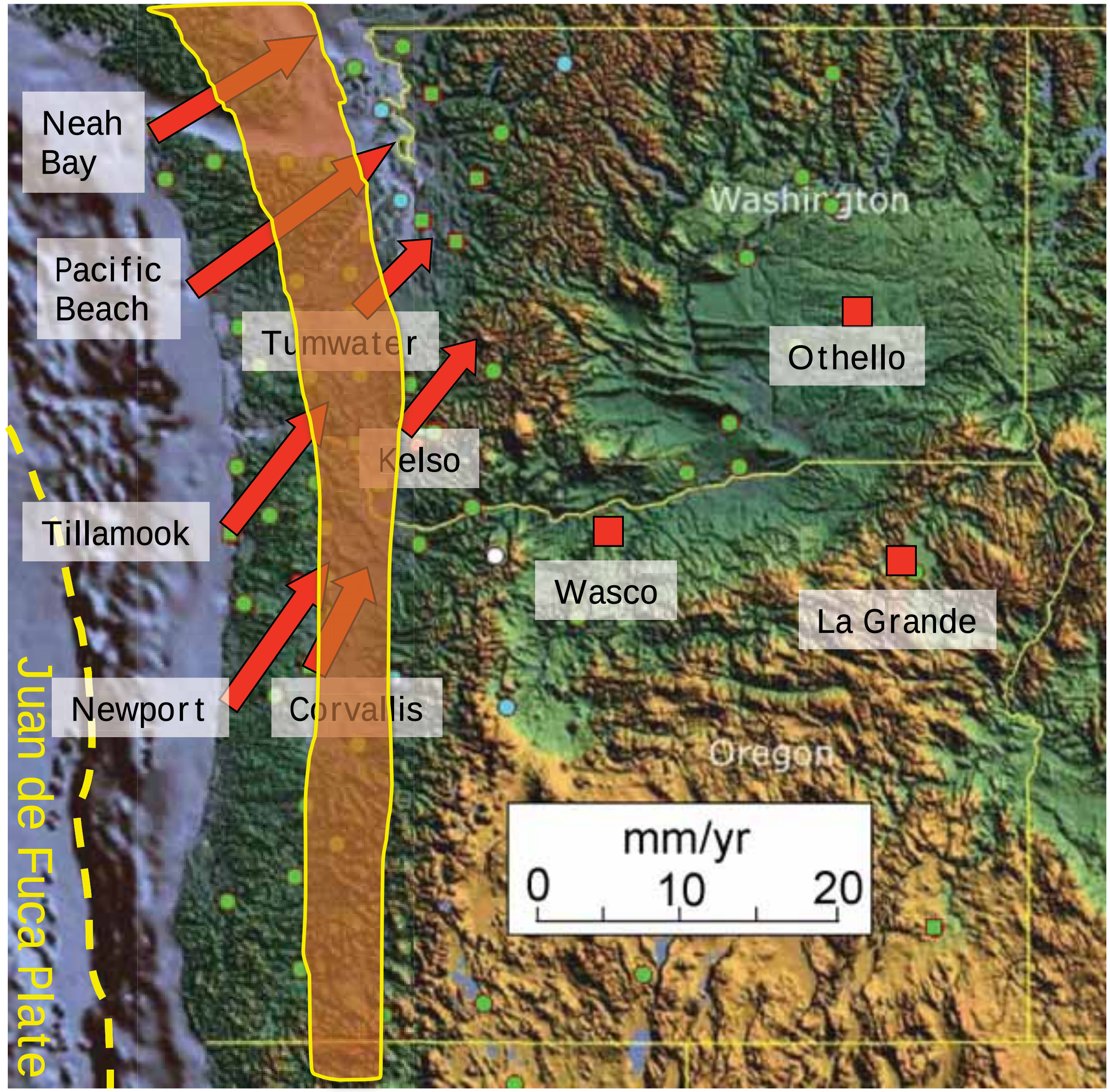
Episodic Tremor and Slip

GPS receivers in western part of the Willamette Valley and Puget Lowlands, as well as the eastern fringe of the Coast Ranges, move in a “sawtooth pattern”.

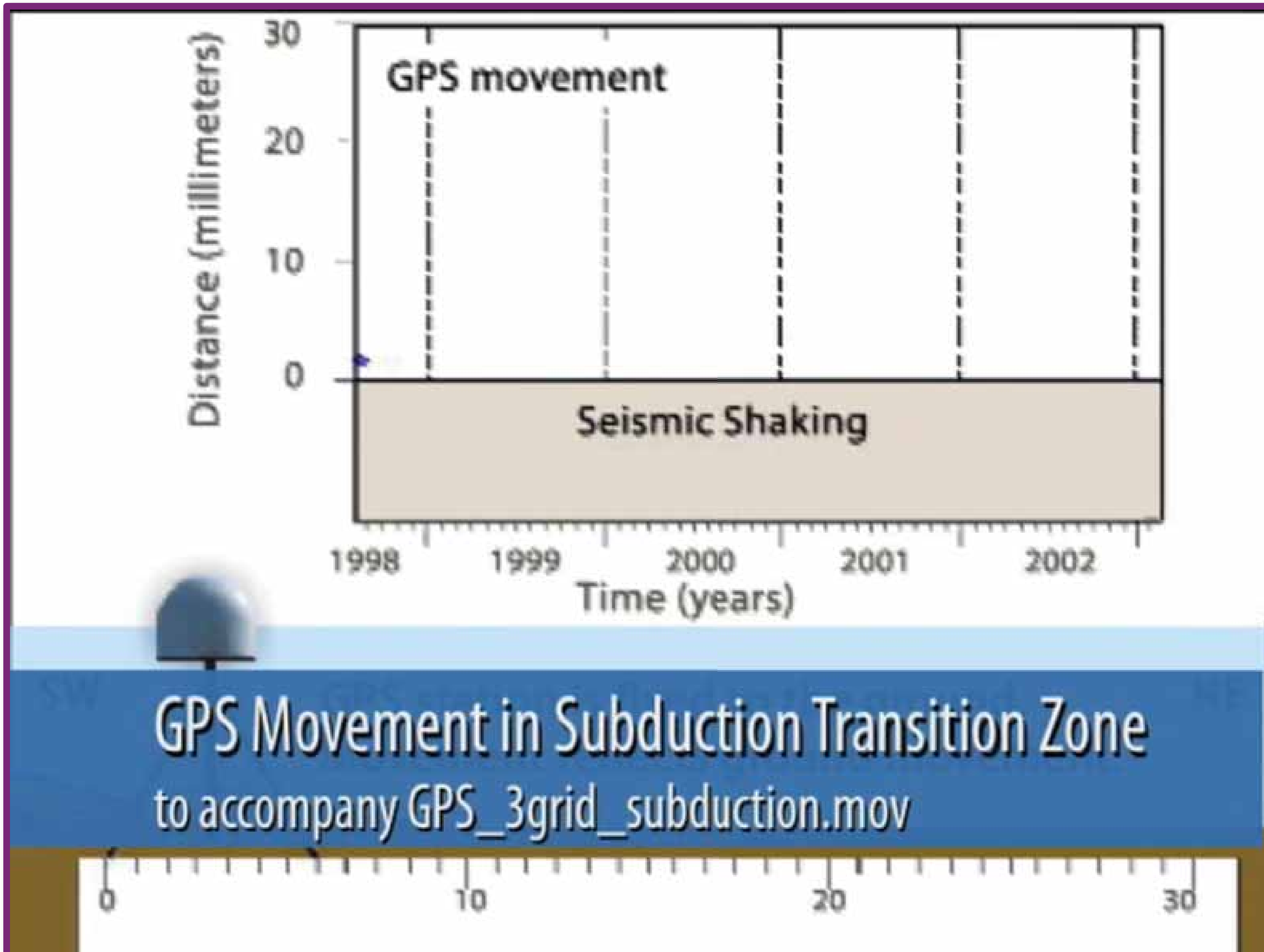
They move NE most of the time but backslide to the SW every 10 to 16 months.

Low-amplitude seismic vibrations accompany the backwards motion.

This is “Episodic Tremor and Slip”, a major new discovery.



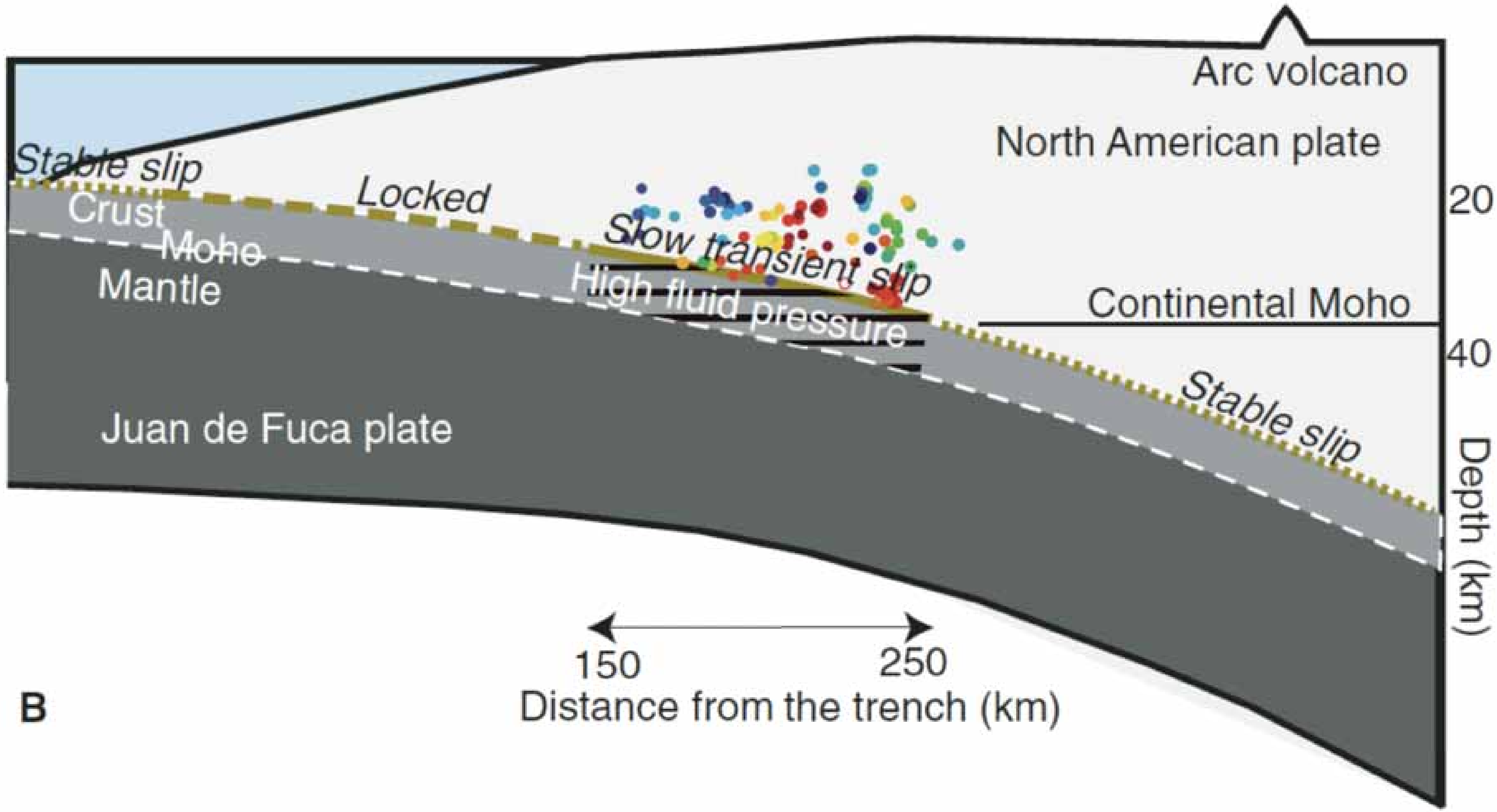
Episodic Tremor and Slip



Animation by JENDA JOHNSON

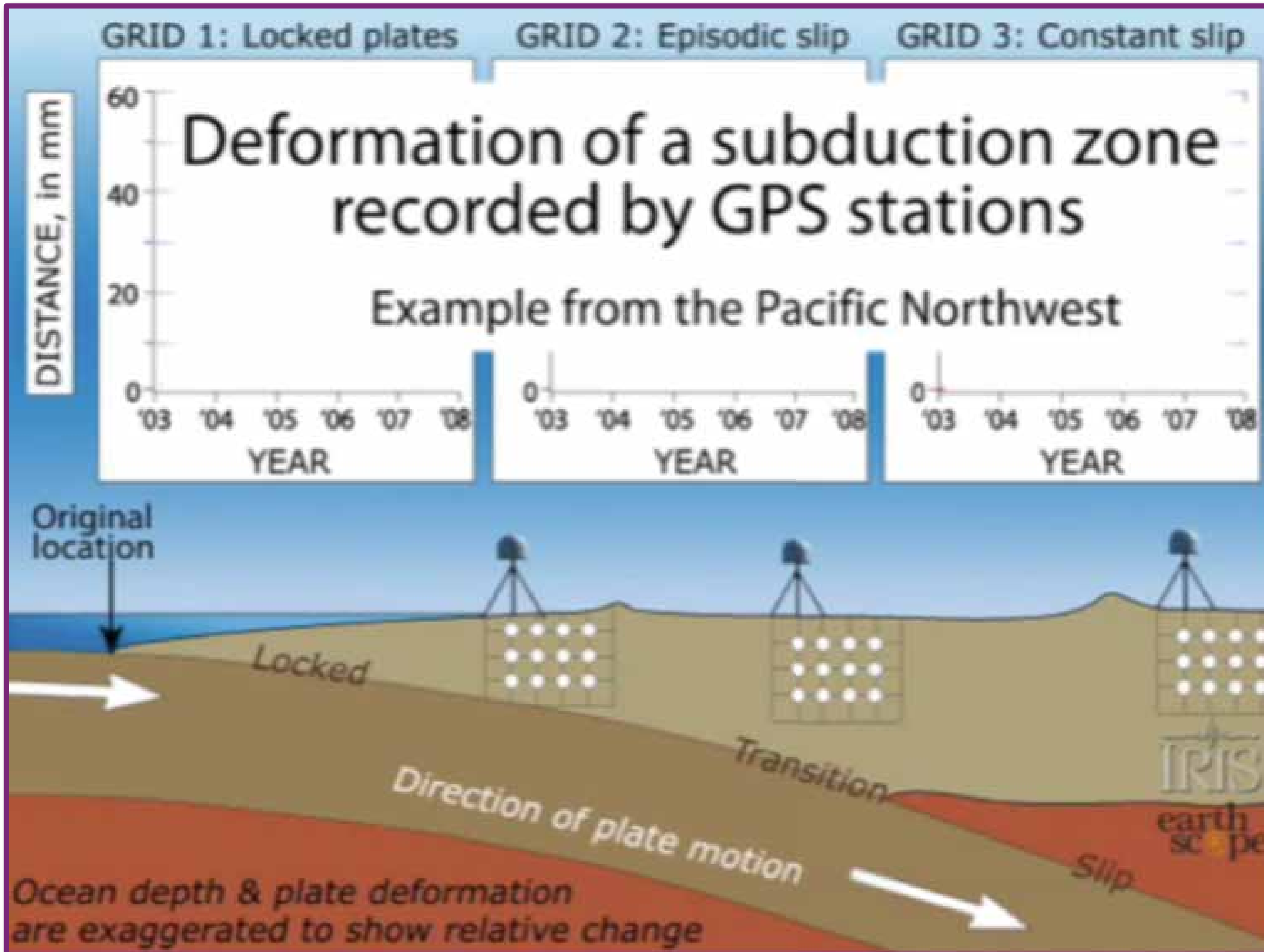
Episodic Tremor and Slip

Two-Block EQ Model



Slow slip between North American and Juan de Fuca plates at 20 – 40 km depth. A transitional behavior between the shallow locked zone and the continuously slipping zone deeper than 40 km.

Episodic Tremor and Slip

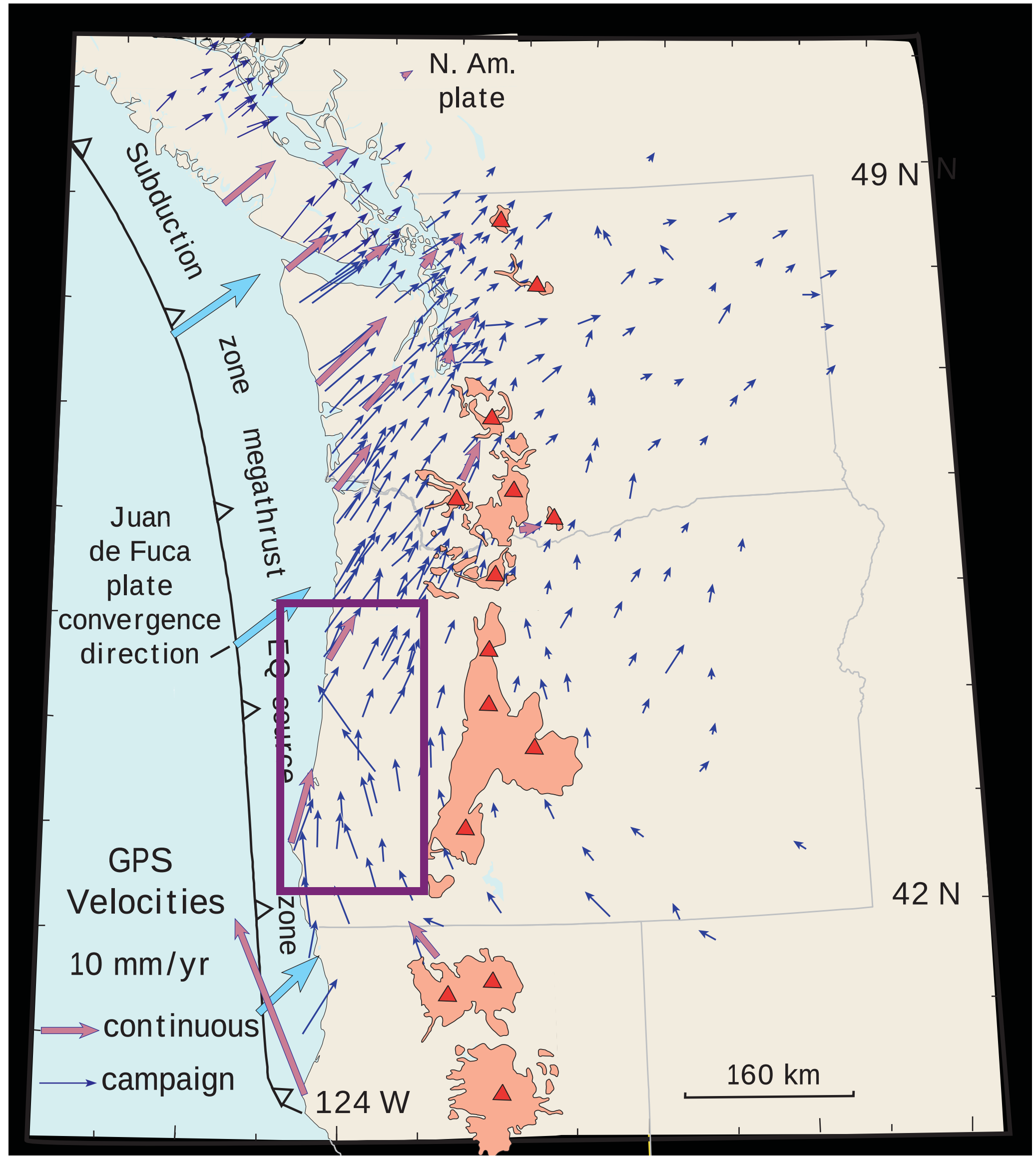


Animation by JENDA JOHNSON

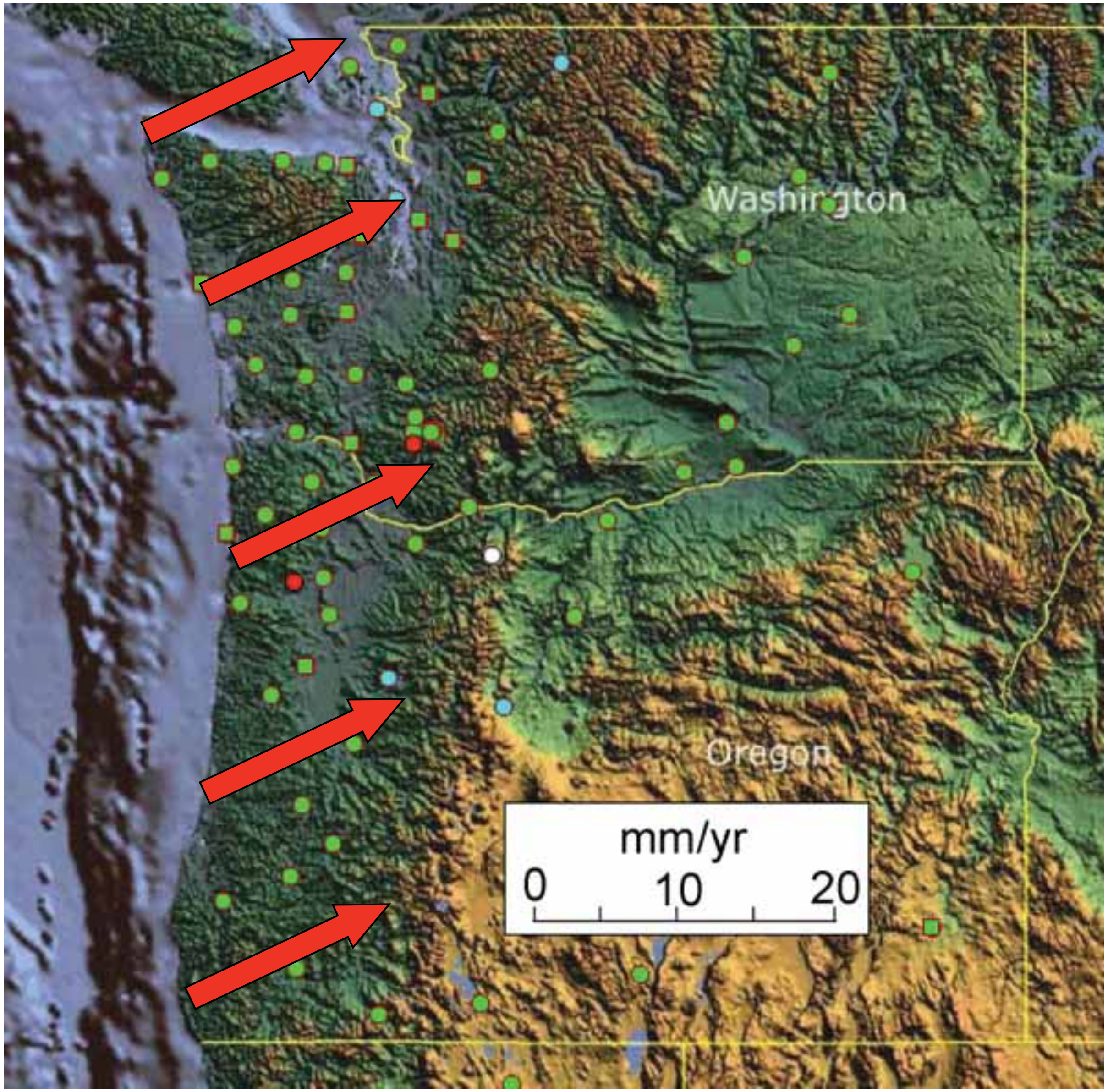
Measured GPS Velocities

What's up with southwestern Oregon?

Shouldn't ALL the velocities vectors on PNW coast be parallel to Juan de Fuca motion as it converges with North America?



Compression of Pacific Northwest Continental Margin

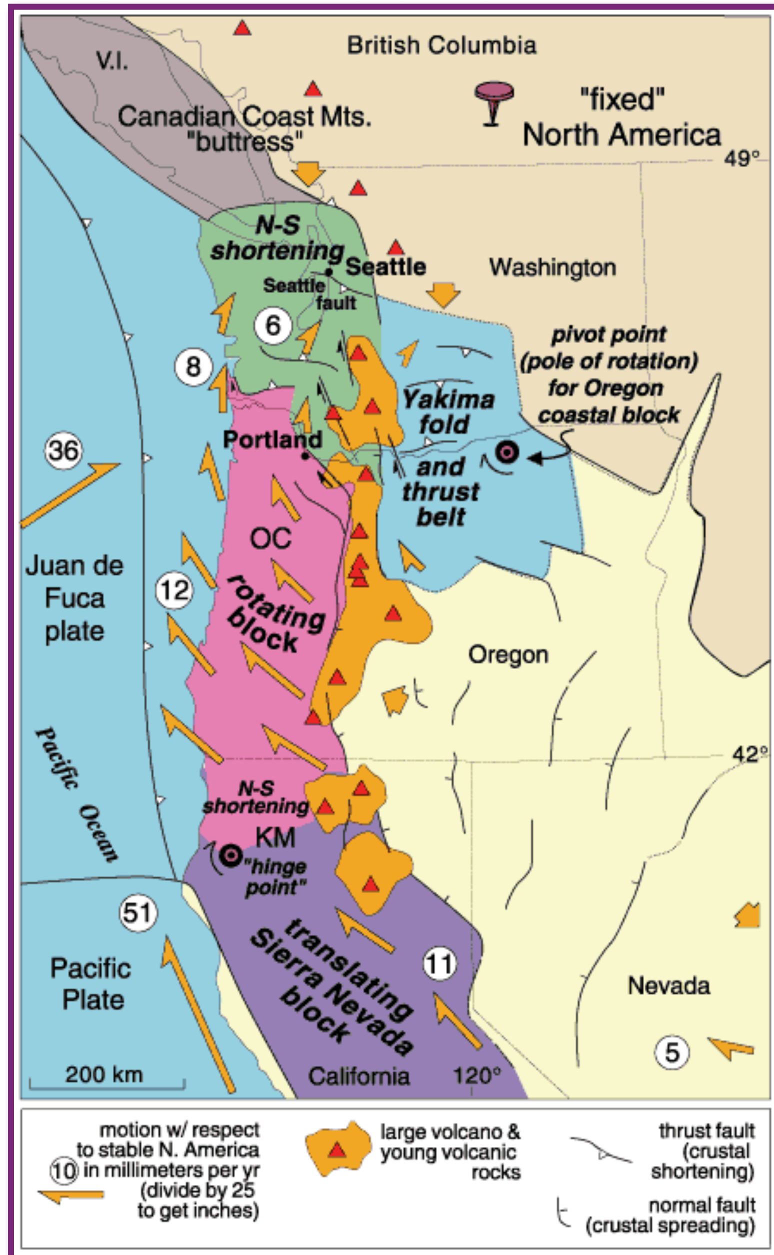


Juan de Fuca – North America convergence ALONE should produce simple pattern of velocities like this.

PNW Crustal Block Model

PNW Crustal Block Motions

These crustal block motions ADD to the motions produced by Juan de Fuca – North America convergence.



Crustal Block Motions + Plate Convergent Motions

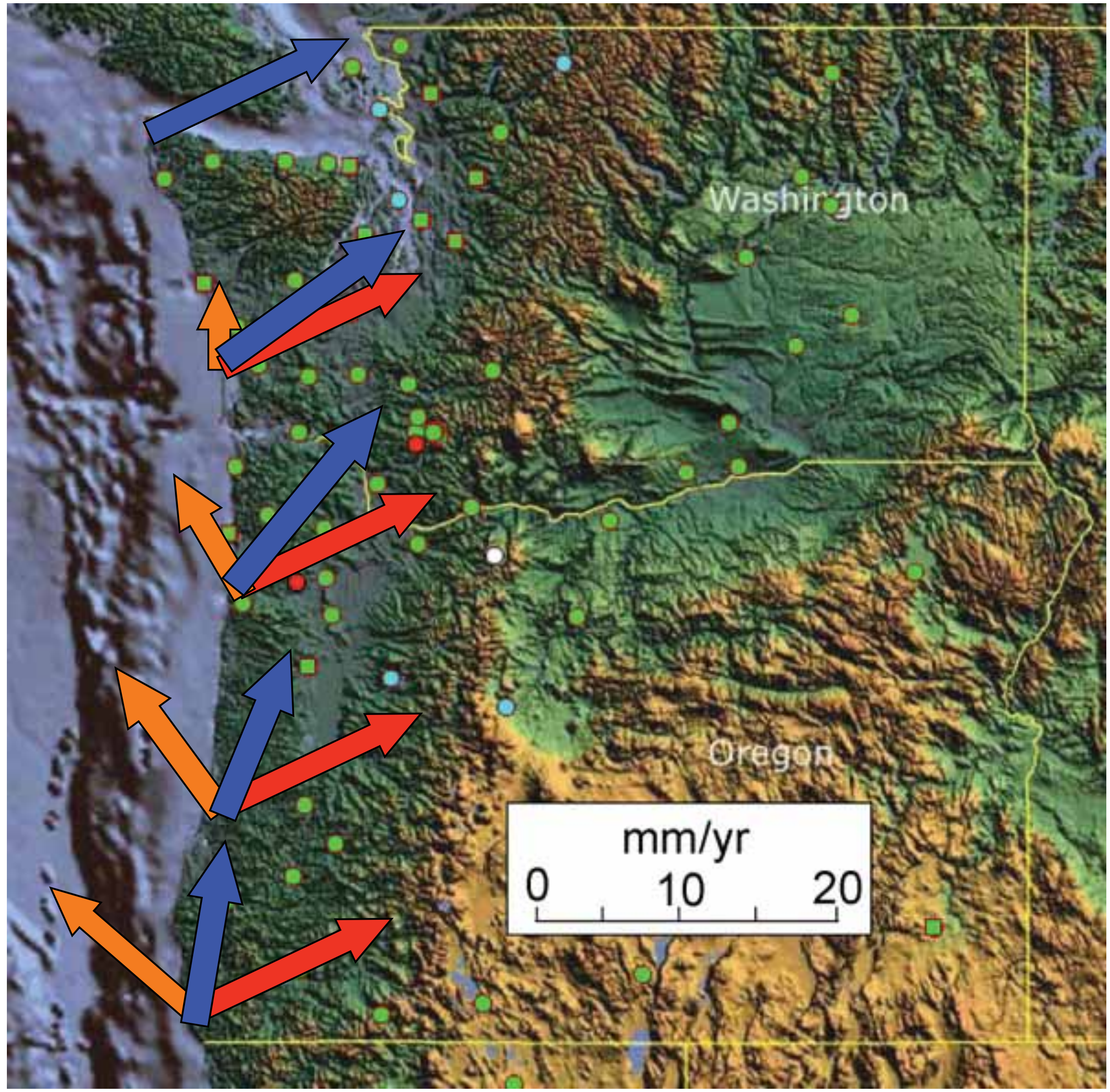
Convergence velocities in red.

+

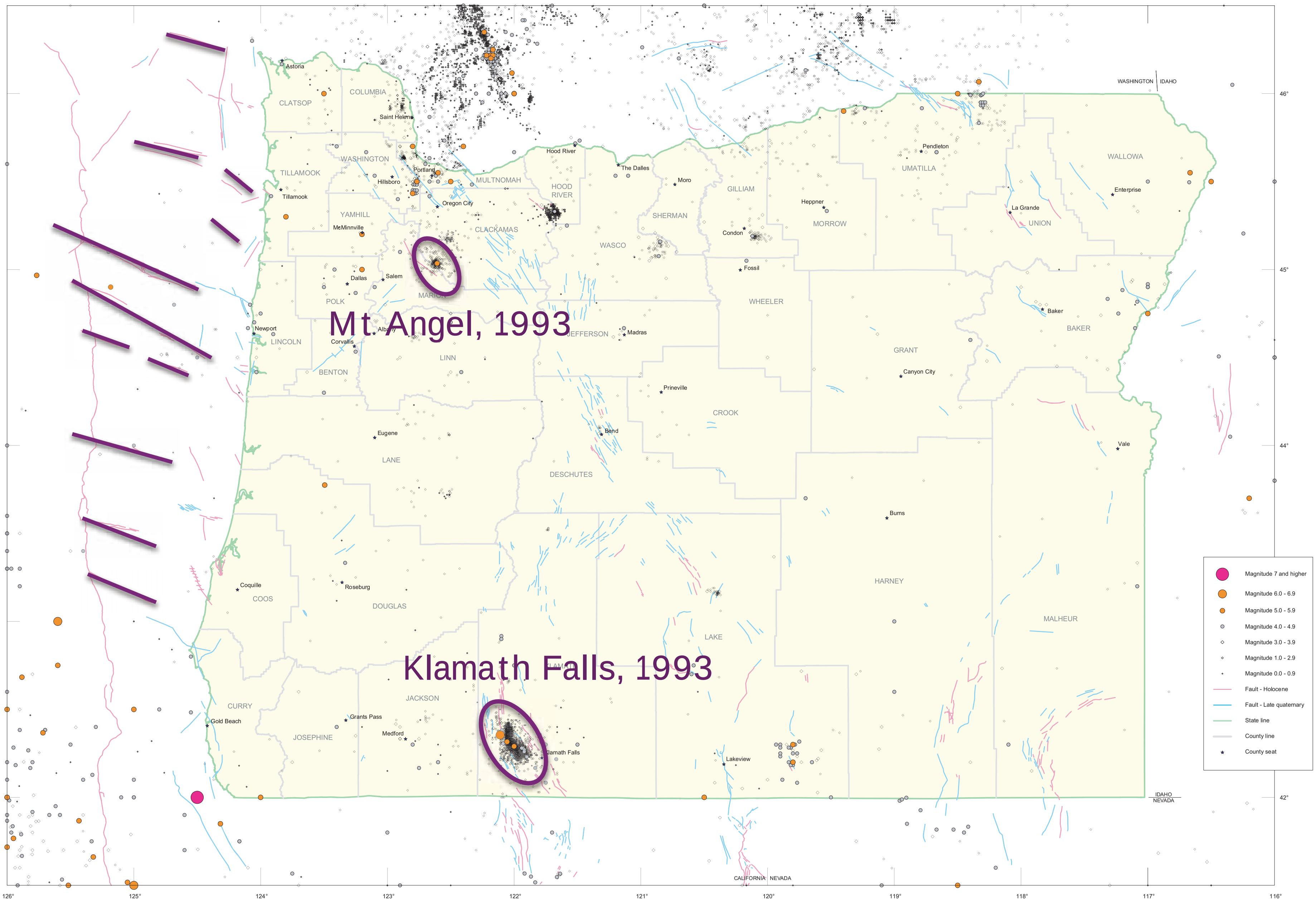
Crustal block motion velocities in orange.

=

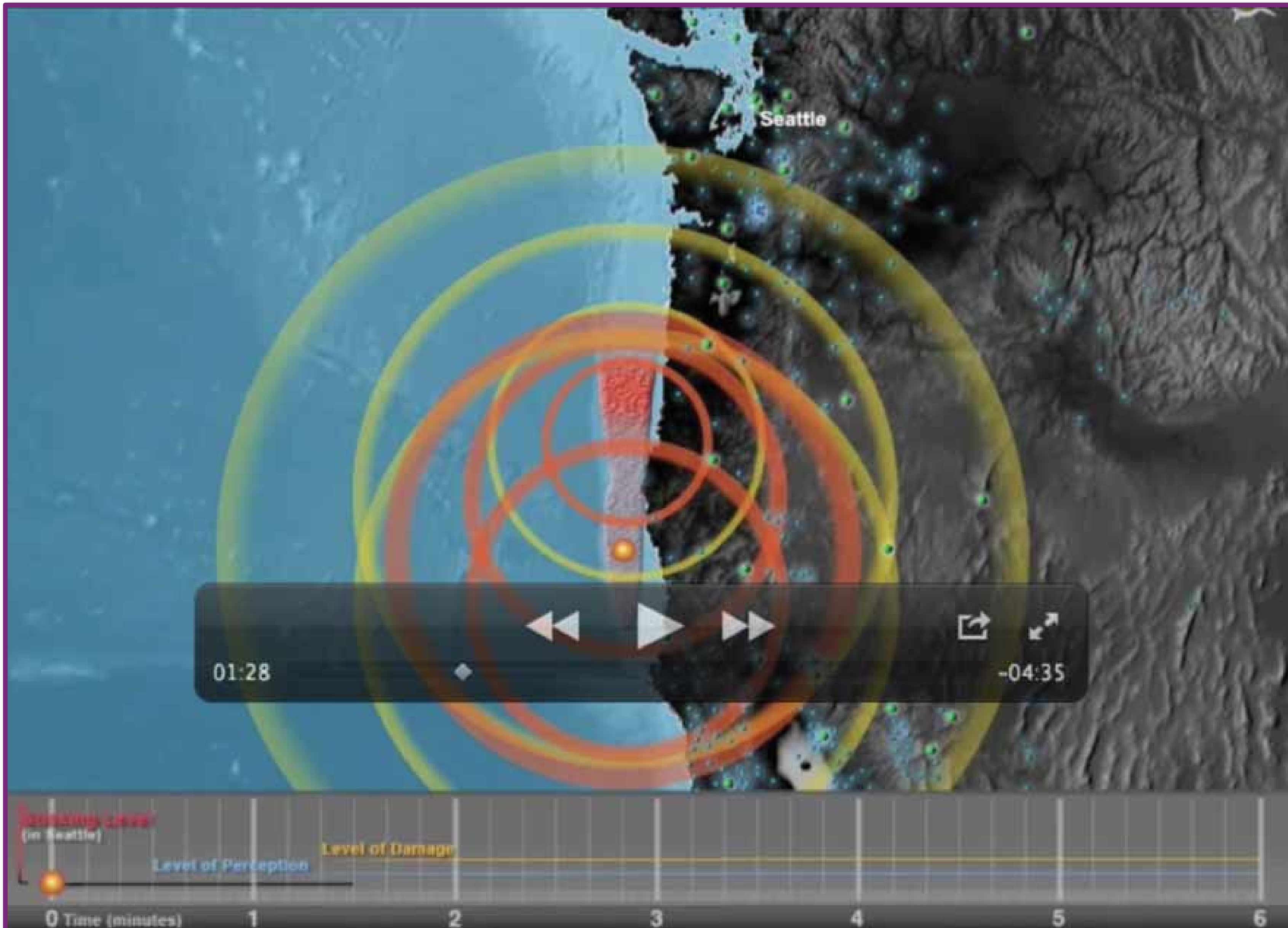
Observed GPS velocities.



Crustal Earthquakes in Oregon 1841 - 2002



The Next Cascadia Great Earthquake



STEVE MALONE, UW Pacific Northwest Seismic Network

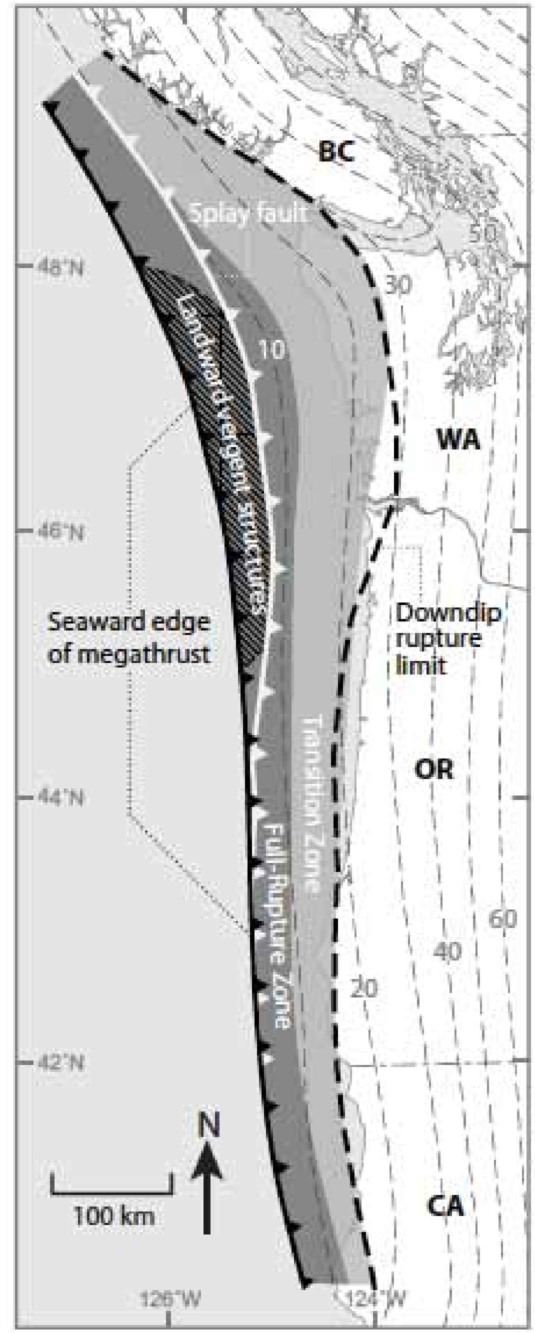
Local Cascadia Tsunami

DOGAMI has published Tsunami Inundation Maps based on modeling of tsunamis generated by great earthquakes on the Cascadia subduction zone.

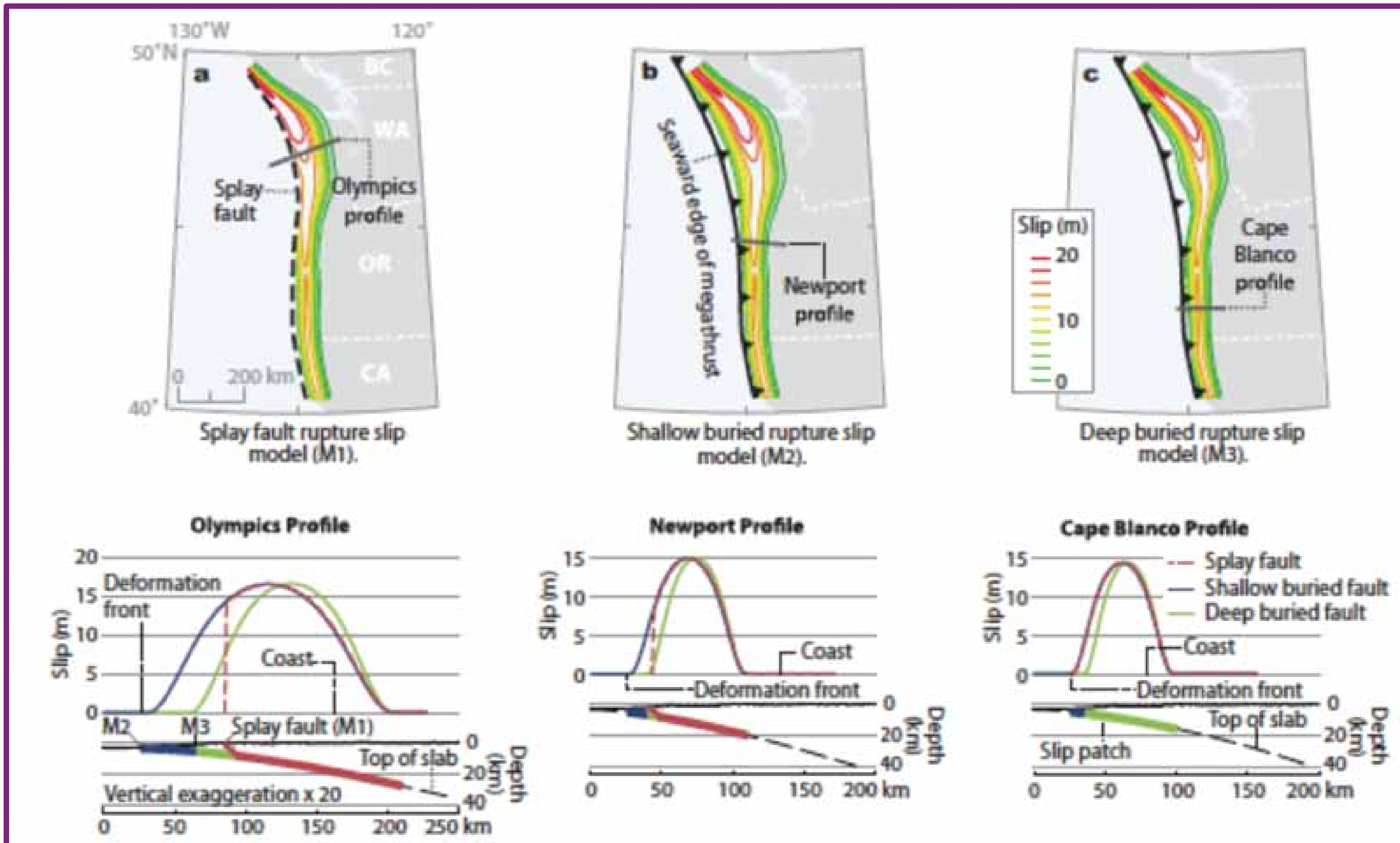
Important factors:

- Western edge of North American plate.
- Displacement during great earthquakes: How much? How deep? A splay fault?
- Bathymetry of ocean floor on continental slope and shelf.
- Shoreline topography.

Note that WA continental shelf is wider than OR continental shelf.



Cascadia Earthquake Displacement Models



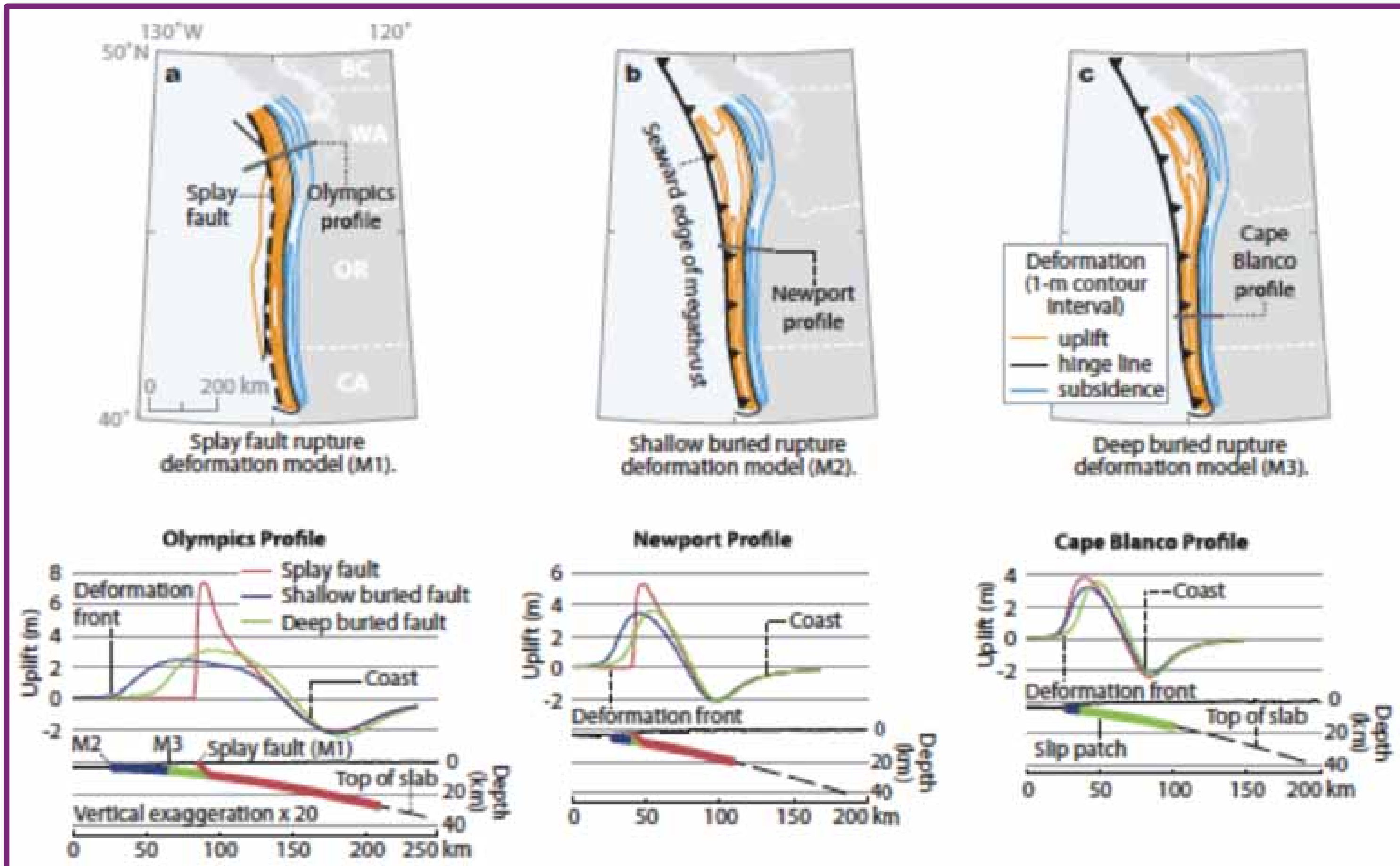
Example for a “medium” size (M8.9) Cascadia earthquake (500-year recurrence time and 15 m offset).

M1: Shallow displacement occurs on splay fault.

M2: Displacement to deformation front.

M3: Displacement stops a few km below the seafloor.

Cascadia Earthquake Vertical-Offset Models



Example for a “medium” size (M8.9) Cascadia earthquake.

M1: Produces 5 m uplift of seafloor offshore from Newport.

M2: Produces 4 m uplift of seafloor offshore from Newport.

M3: Produces 4 m uplift of seafloor offshore from Newport.

Note the change in shape of uplifted seafloor area.

Tsunami Inundation Maps

Local Tsunami Inundation Map for Bandon

SM = “small” M8.8 Cascadia EQ of 9 m displacement (300 years of plate motion).

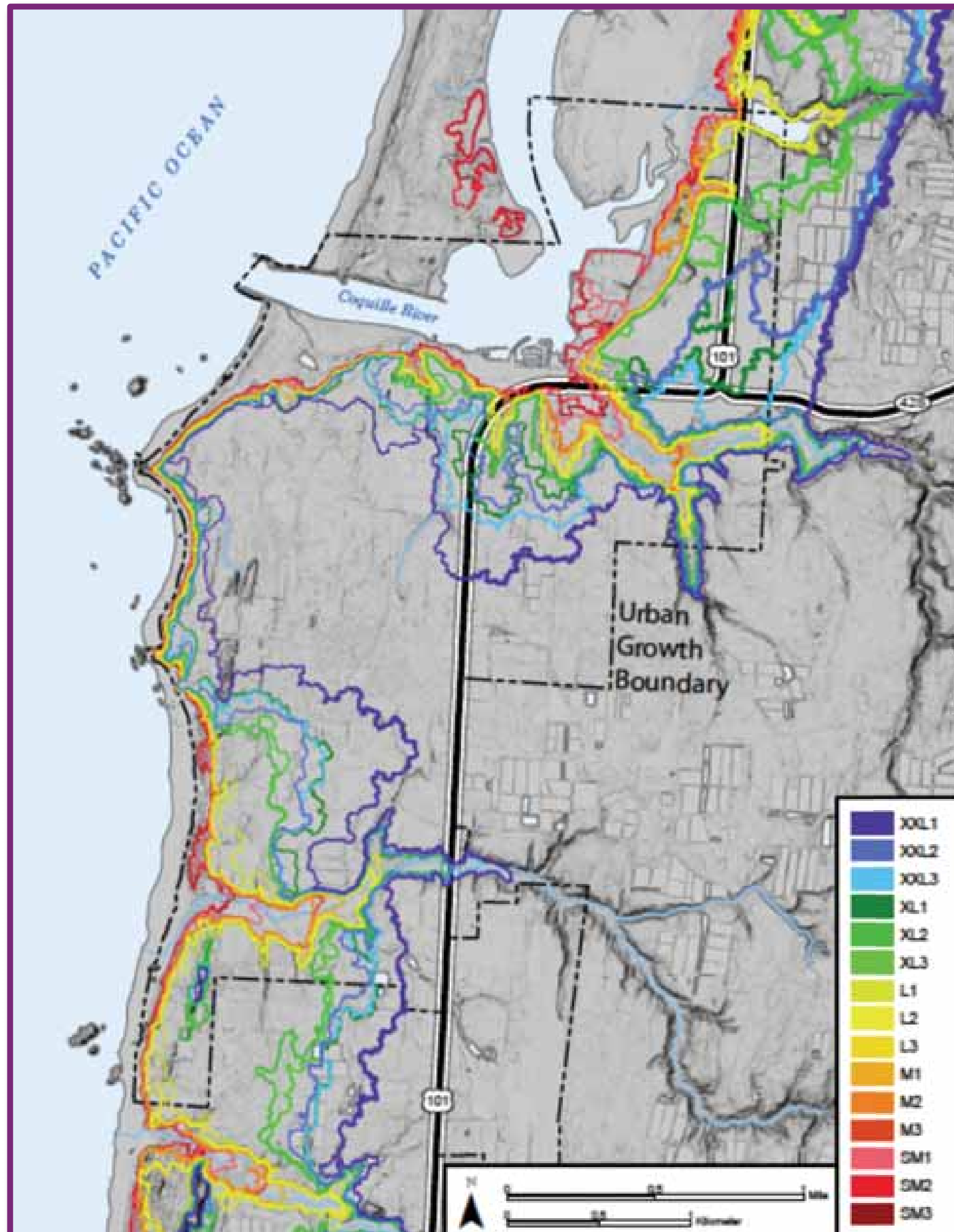
M = “medium” M8.9 Cascadia EQ of 15 m displacement (500 years of plate motion).

L = “large” M9.0 Cascadia EQ of 23 m displacement (750 years of plate motion).

XL = “extra-large” M9.1 Cascadia EQ of 35 m displacement (1100 years of plate motion).

XXL = “extra-extra-large” M9.2 Cascadia EQ of 40 m displacement (1200 years of plate motion).

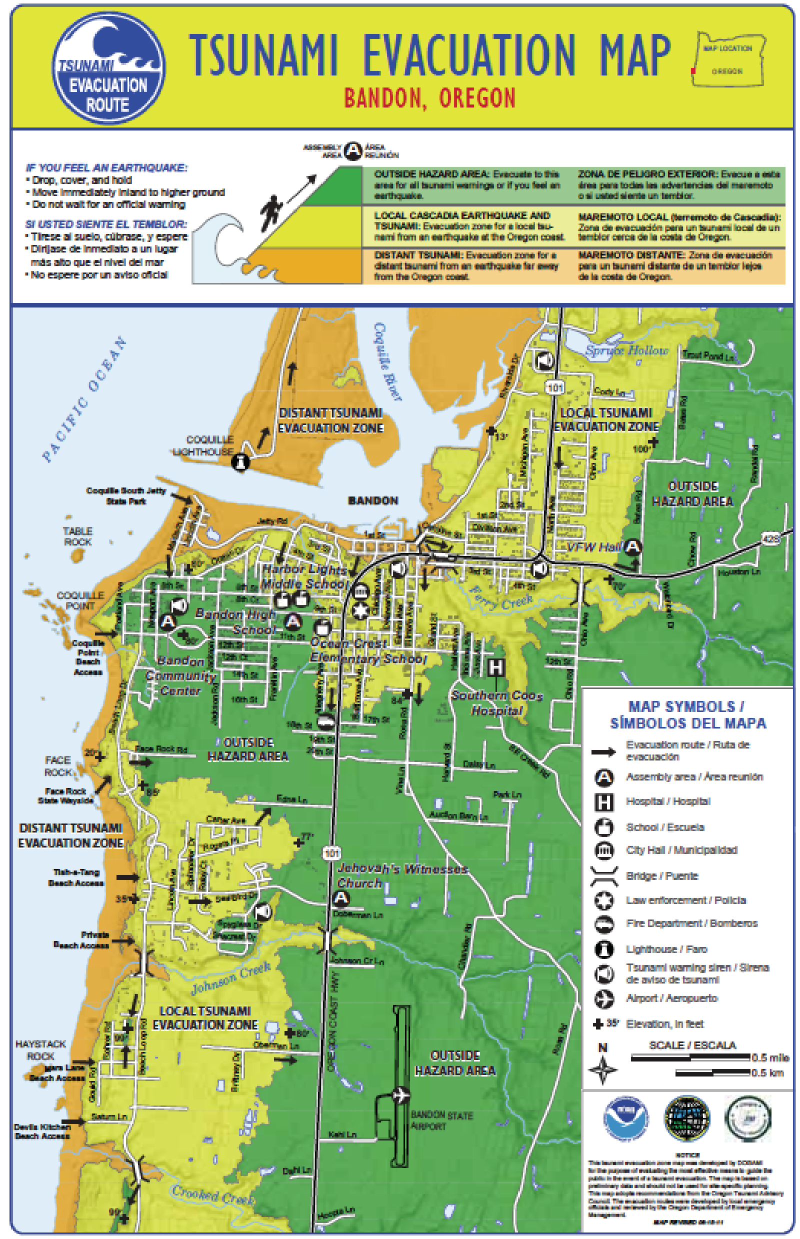
Numbers refer to rupture model.



Tsunami Evacuation Map for Bandon, Oregon

Distant tsunami evacuation zone determined from maximum Alaska tsunami.

Local Tsunami Evacuation Zone determined from maximum Cascadia tsunami.

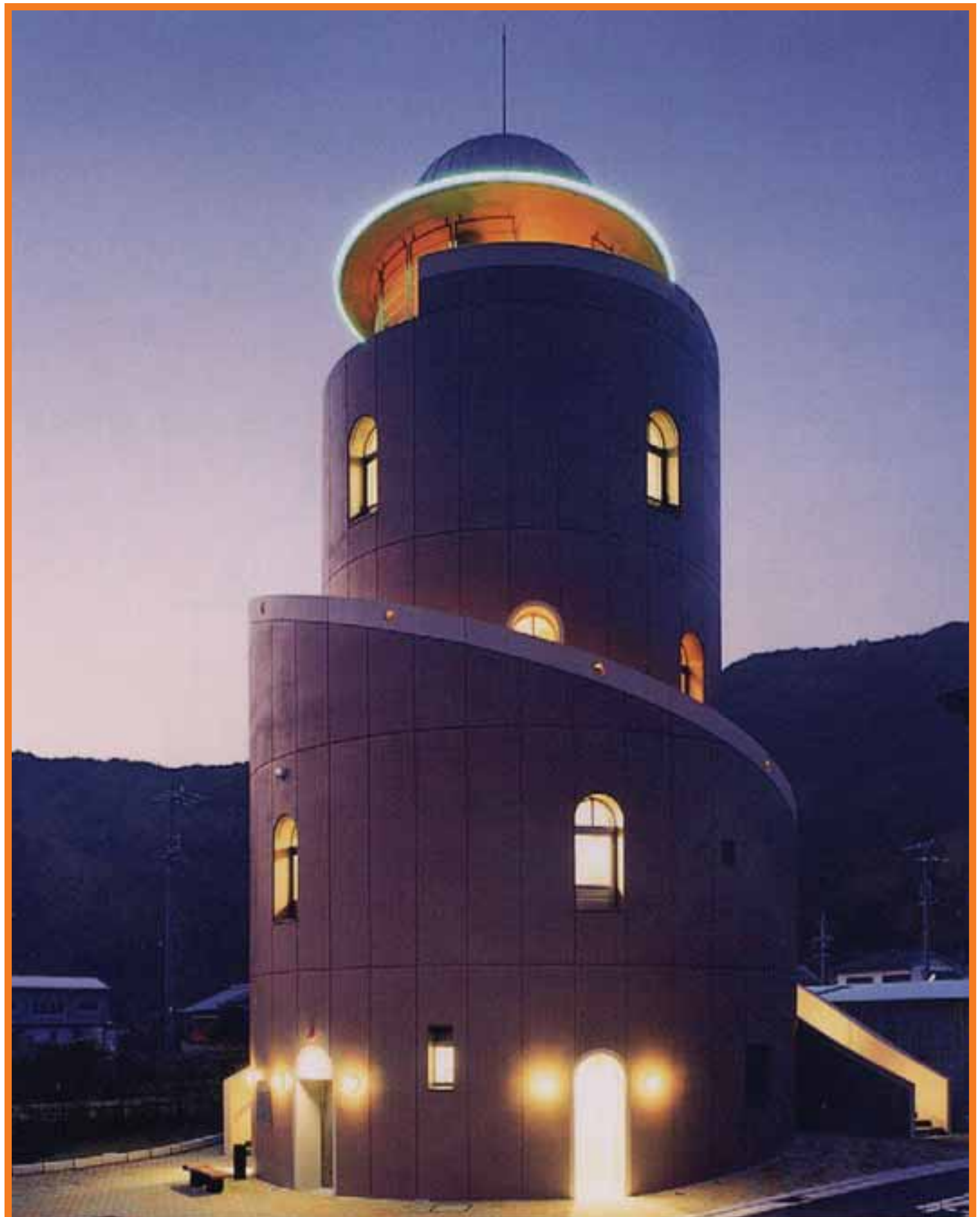


Wave-Tank Tsunami Model

How Does Offshore Bathymetry and Onshore Topography Influence Tsunami Runup?

Vertical Evacuation Building in Japan.

If you can't get out, go up.



NOAA Video on Vertical Evacuation from Tsunamis