COMING TO A SHORELINE NEAR YOU?

... Not Your Ordinary Wave

Modelling of the lost tsunami of 8000 yr BP*

* yr BP means radiocarbon years before 1950

"Lost tsunami" ~ 8,000 yr B.P. "The tsunami was triggered by a debris avalanche from Mt. Etna (Sicily, Italy) which entered the Ionian Sea in the order of minutes (Pareschi et al, 2006, GRL)

http://en.wikipedia.org/wiki/Santorini

The destruction of Santorini was caused by a cataclysmic eruption about 1628 BC, which triggered a tsunami and left a caldera

Deposits of erupted volcanic debris from the cataclysmic eruption ~1628 BC

Excavations at Santorini exhume buried villas and artifacts
250 years ago
November 1, 1755
Lisbon was devastated by an earthquake and tsunami that permanently diminished Portugal as a world power.

> 3 minutes of shaking + tsunami = much damage and 40–50 k killed.

Indian Ocean
December 26, 2004
Megathrust 9.1 earthquake on the Andaman-Sumatra subduction zone triggers devastating tsunami in the Indian Ocean; >230k killed.
The Source of Ordinary Ocean Waves: Wind

The Source of Tsunami Waves: Big Splashes

**Tsunami**

- Mostly, but not always generated by earthquakes
  - Landslides into and under large water bodies
  - Volcanic eruptions into and under the ocean
  - Meteorites impacting the ocean...ala “Deep Impact”.

**Disclaimer:** Tsunami Waves Do Not Look Like This!

**Tsunami - Generation**

- Size of tsunami is related to size of quake.
- Tsunami only form when earthquake causes vertical displacement of the seafloor
  - Tsunami 1
- At what type of plate boundary would you expect tsunami to be generated?
- Which ocean is surrounded by these plate boundaries?

**Wave Characteristics**

- All types of waves have a wavelength, wave height, an amplitude, a frequency or period, and a velocity.

**What makes tsunami waves different?**

- **Wave length**
  - Wind waves: 100 - 200 m
  - Tsunami: 200 - 500 km

- **Velocity**
  - Wind waves: 90 km/hr
  - Tsunami: 950 km/hr (as fast as jet planes) in deep water

- **Period** (time between two successive waves)
  - Wind waves: 5 - 20 sec
  - Tsunami: 10 min to 2 hrs

**Tsunami - on the move**

Velocity depends on water depth. As they enter shallow water, they slow (to freeway speeds) and the wave height grows. The wave actually breaks far off-shore and the “swash” runs-up the shore!
Tsunami Run-up

- The wave that doesn't stop at the beach! Rush inland for up to 30 minutes before being pulled back to help the next wave form!

6.1 m waves; 8-12 max; Mrs. Simms photo

Hilo, Hawaii – 1946 3,800 km from eq

The First Wave Isn't Always the Biggest!

Tsunami wave heights that hit Hawaii after M 9.5 megathrust earthquake off the coast of Chile, 1960

The First Wave Isn't Always the Biggest!

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The First Wave Isn't Always the Biggest!

Whittier, Alaska

Hit by tsunami in March 1964 – 9.2 megathrust EQ in Prince William Sound

Scotch Cap Lighthouse

Aleutian Islands as it looked before the April 1946 earthquake and tsunami. The structure was built in 1940. It sat 40 ft above the sea and was five stories high.

Photograph Credit: U.S. Coast Guard.

Scotch Cap Lighthouse after tsunami generated by M 8.0 earthquake off Alaskan coast.
### Tsunami Waves Are Killers!

<table>
<thead>
<tr>
<th>Date</th>
<th>Cause</th>
<th>Height</th>
<th>Site</th>
<th>Deaths</th>
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</thead>
<tbody>
<tr>
<td>1 Nov 1755</td>
<td>Earthquakes</td>
<td>10 m</td>
<td>Lisbon</td>
<td>36,000</td>
</tr>
<tr>
<td>21 May 1792</td>
<td>Landslide</td>
<td>10 m</td>
<td>Portugal</td>
<td>&gt;4,000</td>
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<tr>
<td>27 Aug 1883</td>
<td>Krakatau collapse</td>
<td>35 m</td>
<td>Indonesia</td>
<td>36,000</td>
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<tr>
<td>15 Jun 1896</td>
<td>Earthquake</td>
<td>29 m</td>
<td>Japan</td>
<td>27,000</td>
</tr>
<tr>
<td>2 Mar 1933</td>
<td>Earthquake</td>
<td>20 m</td>
<td>Japan</td>
<td>3,000</td>
</tr>
<tr>
<td>1 Apr 1946</td>
<td>Earthquake</td>
<td>15 m</td>
<td>Alaska</td>
<td>175</td>
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<tr>
<td>22 May 1960</td>
<td>Earthquake</td>
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<td>Chile</td>
<td>&gt;1,250</td>
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<td>27 Mar 1964</td>
<td>Earthquake</td>
<td>6 m</td>
<td>Alaska</td>
<td>125</td>
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<td>1 Sep 1992</td>
<td>Earthquake</td>
<td>10 m</td>
<td>Nicaragua</td>
<td>170</td>
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<td>12 Dec 1992</td>
<td>Earthquake</td>
<td>26 m</td>
<td>Indonesia</td>
<td>&gt;1,000</td>
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<td>12 Jul 1993</td>
<td>Earthquake</td>
<td>31 m</td>
<td>Japan</td>
<td>230</td>
</tr>
<tr>
<td>2 Jun 1994</td>
<td>Earthquake</td>
<td>14 m</td>
<td>Indonesia</td>
<td>238</td>
</tr>
<tr>
<td>17 Jul 1998</td>
<td>Landslide</td>
<td>15 m</td>
<td>Papua New Guinea</td>
<td>&gt;2,200</td>
</tr>
</tbody>
</table>


### Tsunami Sources in the PNW

**Distant Sources**

- **Good Friday Earthquake and Tsunami, Alaska 1964**
  - Valdez, Alaska
  - 30 dead
  - Shaking causes local landslide along coast which generated a local tsunami. Wave Height 17 m (50 ft)!
  - M. 9.2 megathrust earthquake epicenter: 120 km (75 mi) away!

**Regional Source:**

- **Cascadia Subduction Zone**

### 1964 Good Friday Tsunami slams Washington State Coastline!

- Pacific Beach, home torn in two. Entire house moved 13 m (40 ft) by a (4 m) 13 ft wave. No deaths!
- State Highway 109 - Copalis River Bridge collapses

### Tsunami Sources in the PNW

- **Regional Source:**
  - Cascadia Subduction Zone
Plate Tectonic Setting

**Subduction zone:** India plate subducting beneath Burma plate
- Rate: ~5 cm/year
- Dip of interface: ~10°

**2004 Earthquake**
- Date: December 26, 2004
- Magnitude: 9.0
- Rupture length: 1200 km
- Rupture width: 100 km

**Most Recent Previous Great Earthquake**
- Date: November 24, 1833
- Magnitude: 8.8 – 9.2
- Recurrence interval: 230 years

**Tsunami Characteristics**
- (extremely preliminary estimates from media accounts)
  - Peak tsunami height in the near-source area: ~80 ft in Indonesia
  - Peak tsunami height in Somalia (8 hours travel time and 3300 mi away): ~10 ft
  - Affected the entire Indian Ocean

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**CASCADIA SUBDUCTION ZONE**

**Regional Source**
- First recognized in 1980s.
- Cascadia tsunami have happened multiple times in the past.
- Last major one 1700 A.D.
- < 1-hour warning, not 4 hours!
- Waves up to 10 m (30 ft) can hit the Washington shoreline.

**Tsunami Sources in the PNW**
- Local Sources within the Puget Sound!!
  - Landslides into the Sound
  - Submarine landslides
  - Faults below the Sound (e.g. the Seattle fault)

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Evacuation route map for Westport, Washington.
http://www.emd.wa.gov/hazards/haz_tsunami.shtml
Landslides into the Puget Sound

1949 Landslide Into Tacoma Narrows. Created 2-5 m (6-8 ft) wave in Gig Harbor before it sloshed back to hit Salmon Beach.

Lituya Bay, Alaska, landslide-generated tsunami - July 9, 1958. The rockslide generated a 526 m splash-up immediately across the bay, and razed trees along the bay before leaving the bay and dissipating in the open waters of the Gulf of Alaska.

It could be much worse!

Submarine Landslides

- Most likely to happen at a major delta in the Puget Sound: Duwamish, Nisqually, or Puyallup
- Can happen with little or no warning; may be associated with an earthquake, maybe not.
- No way to stop it.
- Wave of up to 50 ft will hit in seconds

trimline

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Nisqually River Delta and others have high sedimentation rates.

Fig. 5-10, p.105

(1a) Seafloor snaps up, pushing H2O; (1b) sea sfc drops & forms trough; (2) displaced water resurges = crest; and (3) gravity restores water level to equilibrium & sends waves in both ways.

This northwest–southeast cross section of Kilauea volcano shows the probable failure surfaces that lead to collapse of the volcano’s flanks. See cross-section location as line A–A’ in map Figure 5-20.
Cliffs are remnant scarp of ancient collapse.

A large landslide from La Palma, Canary Islands; huge waves would reach the east coast of North America in 6–7 hr.

A 1-meter-high tsunami wave in the open ocean slows in shallower water near shore, so if the wave volume remains the same, its wavelength shortens and its amplitude rises.

Cascadia oceanic trench to the north and the San Andreas transform fault.

Tsunami sand from a megathrust earthquake deposited in 1700 over dark brown peat in a British Columbia coastal marsh. The scale is in tenths of 1 meter.
Simplified sketch showing tsunami sand deposited immediately after a subduction earthquake when a tidal marsh suddenly drops below sea level.

Fig. 5-35, p.120

Submarine Landslide off Puyallup Delta
Northern Pacific RR dock
Commencement Bay – 1894
Took out 100 m of docks, 2 dead. Wave >3 m (10 ft) wash Old Town section.

Old Town section.

Faults below the Sound
What would happen if the Seattle Fault broke?!

Seattle Fault: south dipping reverse fault

The Three Types of Tsunami have vastly different warning times!

<table>
<thead>
<tr>
<th>Type</th>
<th>Source</th>
<th>Warning Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trans-Pacific</td>
<td>Alaska and Asia</td>
<td>4 or more hours</td>
</tr>
<tr>
<td>Regional</td>
<td>Cascadia Subduction Zone</td>
<td>0.5 to 3 hours</td>
</tr>
<tr>
<td>Local</td>
<td>Local earthquakes and landslides</td>
<td>1 minute</td>
</tr>
</tbody>
</table>
Who Might Be Impacted?
- Shore-side homes, schools, businesses
- Ports and Harbors
- Transportation systems/ utilities
- Toxic Waste sites
- Coastal ecosystems
- You!!

Hazard Awareness Program
How do you survive a tsunami?

How to survive a tsunami
- Heed natural warnings
- Heed official warnings
- Expect many waves
- Head for high ground and stay there
- Abandon belongings
- Don't count on roads
- Climb a tree
- Climb onto something that floats
- Expect waves to leave debris
- Expect quakes to lower coastal land

Summary
- Tsunami are more than just big waves.
- They are fast, powerful, destructive.
- Washington is at risk from distant, regional, and local tsunami sources.