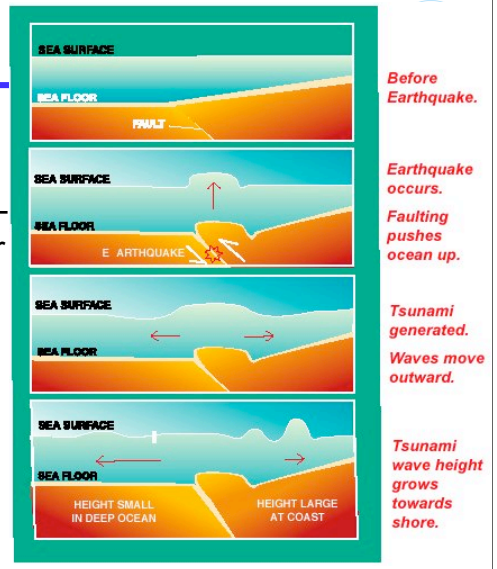
Tsunami

- Japanese term
  - Tsu = harbor, Nami = wave
  - Both singular & plural
- "Tidal Wave" a misnomer
  - Nothing to do with tides
    - Except both are waves on water
  - "Seismic sea wave" better
- What causes tsunami?
  - Usually major submarine quakes
  - But also volcanoes, landslides, iceberg falls

Tsunami

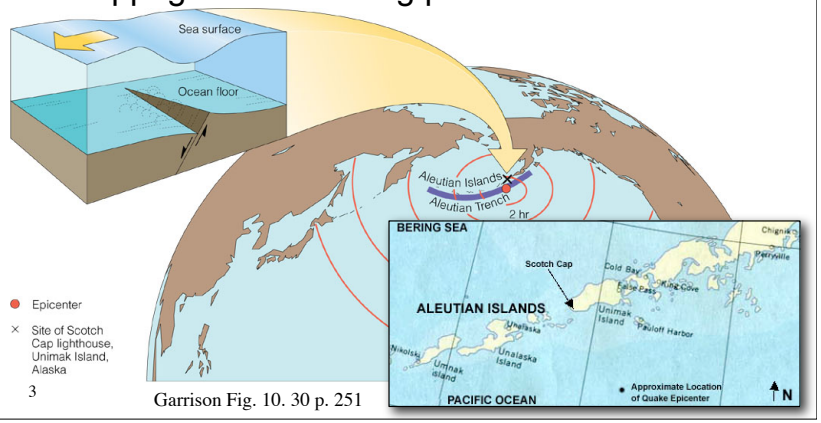
- Most common cause
  - Vertical displacement of sea floor
    - Uplift (pictured) or subsidence
    - Slippage on a quake fault
  - Hill or hole at sea surface
    - Spreads outward



www.globalsecurity.org/eye/andaman-pix2.htm

Seismic Causes

- Vertical movement on 2 sides of a fault
  - Slippage of subducting plate



Garrison Fig. 10. 30 p. 251

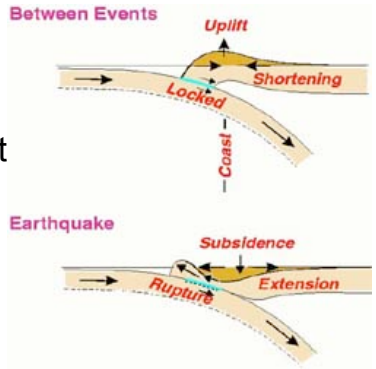
Seismic Causes

- Classic subduction quake tsunami
  - 7.4 on Aleutian trench April 1 1946
    - Sea floor uplift
  - Scotch Cap lighthouse 90 miles away
    - 100-ft. wave struck ~48 minutes later, 5 killed

Garrison p. 251, www.usc.edu/dept/tsunamis/alaska/1946/webpages/index.html

Northwest Seismic Causes

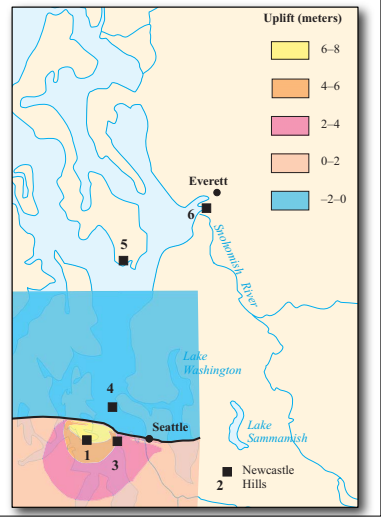
- Cascadia subduction zone
  - Between quakes, sea floor sinks & continent rises
    - Olympic coast rising ~3 mm/yr
  - Rupture: sea floor lifts, continent subsides
    - Falls ~ 1 meter



http://www.pnsn.org/HAZARDS/CASCADIA/land_levels.html

Northwest Seismic Causes

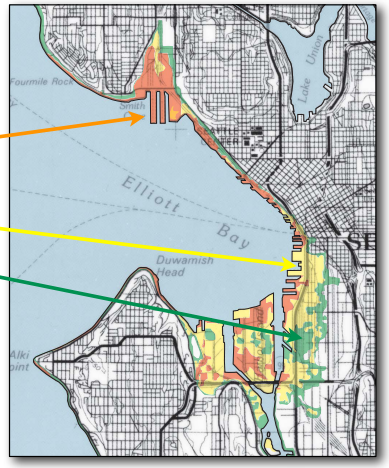
- Seattle Fault
  - Crust blocks squeezed by plate collision
  - Crust south of fault rose ~20 ft.
    - ~7 m (20 ft.)
    - 900 AD
    - Crust north of fault fell
  - Modeled scenario for future quake & tsunami



www.dnr.wa.gov/geology/pdf/ofr03-14.pdf

Seattle Fault

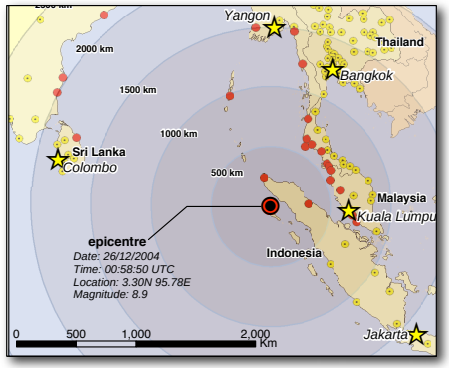
- Map of modeled tsunami flooding
  - Downtown & port
    - 2–5 m ">Head-high"
    - 0.5-2 "Knee to head-high"
    - 0–0.5 "<Knee-high"
    - Run-up higher than actual height of wave
  - Animation
    - http://nctr.pmel.noaa.gov/animations/seattle_cap.qt



www.dnr.wa.gov/geology/pdf/ofr03-14.pdf

Indian Ocean Tsunami

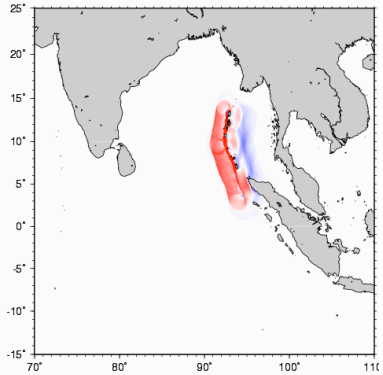
- Source at NW tip of Indonesia
  - Banda Aceh
  - Magnitude 9.0
    - Largest since 1964
  - 231,452 deaths
    - Highest toll in recorded history
  - Damage reached E. African coast
  - Waves detected in Pacific & Atlantic

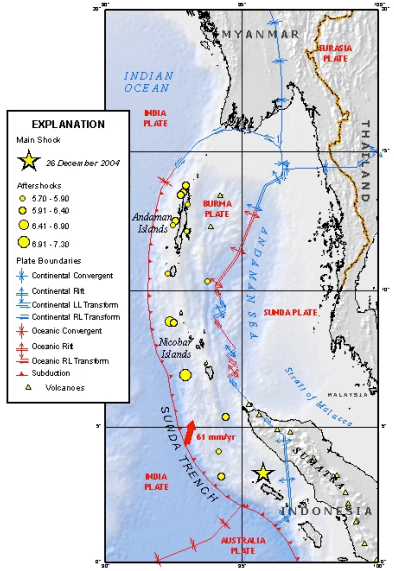


www.globalsecurity.org/eye/andaman-maps.htm

Indian Ocean

- Subduction zone in E. Indian Ocean

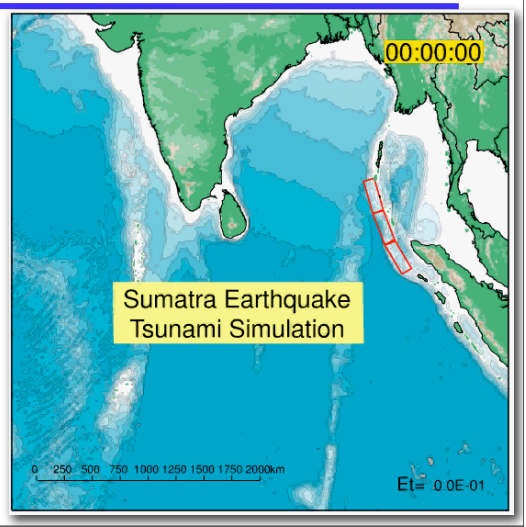




9 www.globalsecurity.org/eye/andaman-sri-lanka.htm www.globalsecurity.org/eye/andaman-maps.htm

Indian Ocean

- Subduction zone in E. Indian Ocean

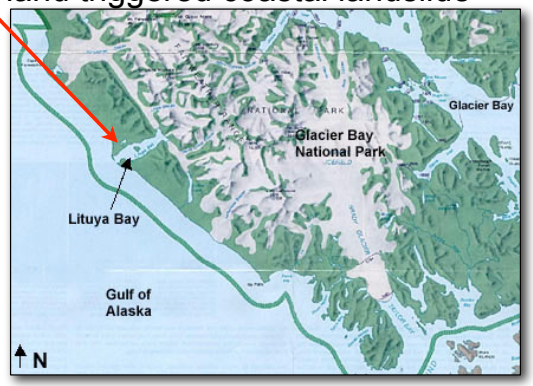


http://es.ucsc.edu/~ward/indo.mov

10

An Unusual Tsunami

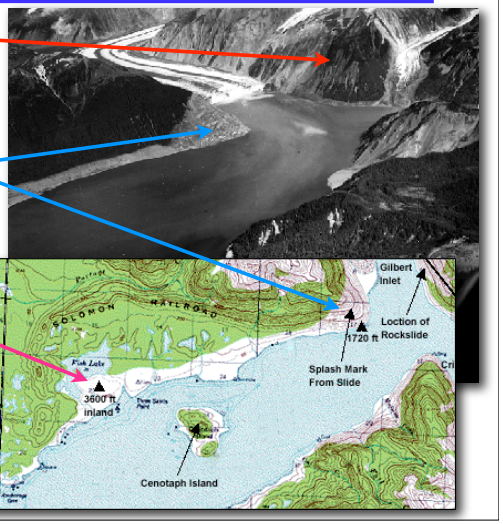
- Lituya Bay, Alaska July 7 1958
  - 8.0 quake on land triggered coastal landslide
  - Caused wave in enclosed bay
  - Wall of water 100 ft. high
    - 2 boaters killed, some survived



11 www.usc.edu/dept/tsunamis/alaska/1958/webpages/index.html

Lituya Bay

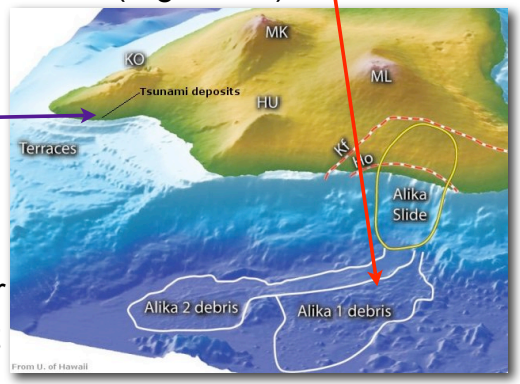
- Site of slide
  - Largest run-up in recent history
- 1720 feet up hillside
- Up to 3600 feet inland



12

Hawaiian Landslide Tsunami

- Sonar evidence of huge landslide deposits
  - Kona coast of Hawaii (Big Island)
- Coral debris 60 m above sea level
  - Both dated to ~110K years
  - Island was ~300 m higher
  - Run-up height ~1000 ft.



http://www.mala.bc.ca/~earles/kohala-tsunami-sep04.htm

Future Mega-Tsunami?

- La Palma, Canary Islands
  - Volcano slope unstable?
    - Landslide feared from eruption
- 100-meter tsunami?
  - Strikes Morocco in 10 min.
  - 50-m wave reaches U.S. East Coast in 8–9 hours
- Many scientists skeptical
  - Local tsunami only?

archives.cnn.com/2001/TECH/science/08/29/tidal.wave/index.html
www.iberianature.com/material/megatsunami.html

http://volcano.und.edu/vwdocs/volc_images/africa/lapalma.html

What Affects Tsunami Size?

- Area of sea floor that changes elevation
  - Length of subduction zone that ruptures
  - Vertical displacement distance
  - Displace the “water column”
  - Ripples travel outward from epicenter
- Some large quakes do not generate tsunami
  - Or any at all
  - Reasons not fully understood
  - Strike-slip (transform) quakes often do not displace the sea surface much

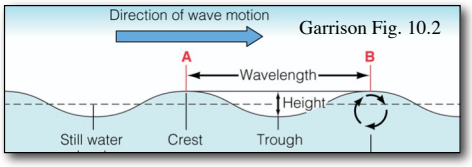
Northwest Scenario

- Up to 1100 km length of subduction zone rupture
  - 50–150 km wide
  - Shaking could cause damage inland in Seattle. Portland, Vancouver
- 1700 AD tsunami height
  - Estimated @ 10 m
  - 15-40 minutes to reach coast
- 500-600 year average recurrence interval
  - But some have been less than 300

http://earthquake.usgs.gov/regional/pacnw/paleo/greateq/conf.html

Tsunami Anatomy

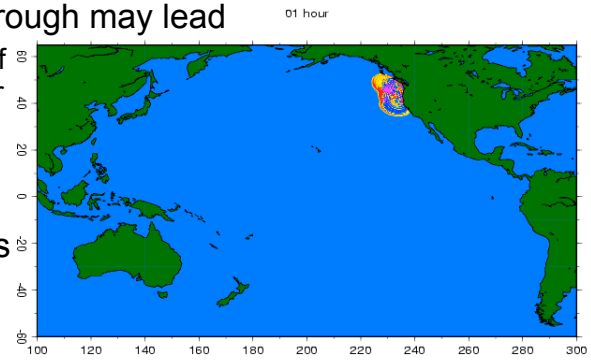
- A classic progressive wave
  - Crest = high point
  - Trough = low point
  - Height = vertical elevation of crest above trough
  - Wavelength = horizontal distance between crests or troughs
  - Period = time passage between successive crests or troughs
    - = Time to travel 1 wavelength



Garrison Fig. 10.2

Tsunami Propagation

- Wave sets travel radially out from source
  - "Pebble in a pond"
  - Crest or trough may lead
    - Trough if sea floor drops
  - Height gradually decreases with distance



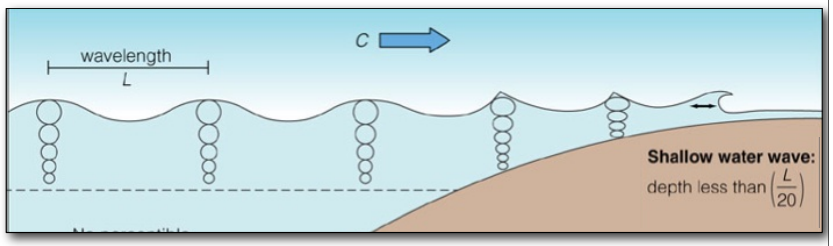
www.pgc.nrcan.gc.ca/press/images/2003JB002521-animation.gif

Tsunami Propagation

- Height generally very low in deep ocean
  - Less than 1 meter
  - Very long wavelength
    - Hundreds of kilometers
  - Very long period
    - 5–20 minutes between crests
  - May not be noticed by ships at sea
- Height increases as waves approach shore
  - Wave motion occurs over entire depth of "water column"
  - Energy squeezed into a shallower depth

Tsunami Speed

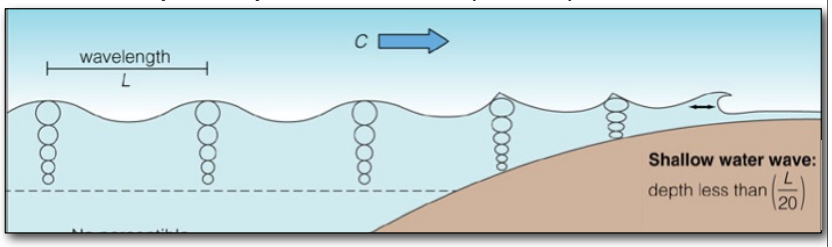
- "Shallow-water wave"
  - Defined as wave with length >20 times depth
    - Or depth <1/20 (5%) of wavelength
  - Speed controlled by depth of water
    - Friction against the bottom



Garrison Fig. 10.6 p. 233

Tsunami Speed

- "Shallow-water wave"
  - Tsunami waves so long that all the ocean is "shallow"
  - 5000 m abyssal plain vs. wavelength ≤200 km
  - Except deepest trenches (11 km)



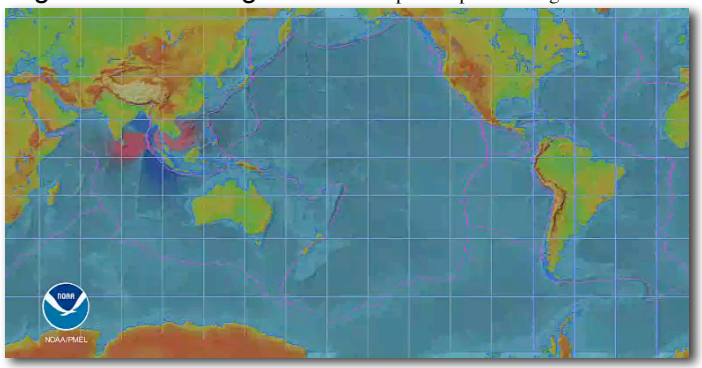
Tsunami Speed

- Speed controlled by depth of water
  - Wave motion reaches to the bottom
- Speed calculated from water depth
  - C (m/sec) = "Celerity" $\sqrt{gd}$
    - g = gravitational acceleration 9.8 m/sec^2
    - d = depth in meters
    - Garrison p. 249
  - Speed range 500–1000 km/hr
    - = 300–600 miles/hr
    - Speed of a jetliner!
  - Wavelength up to 500–650 km

Tsunami Speed

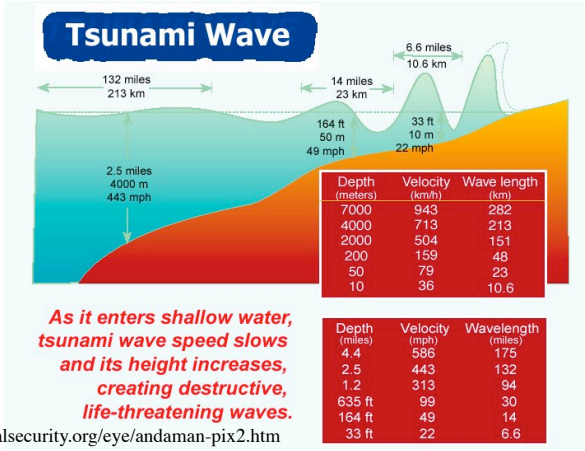
- Wave front affected by depth of water
  - Slows in shallower water
    - E.g. mid-ocean ridges

http://nctr.pmel.noaa.gov/animate.html



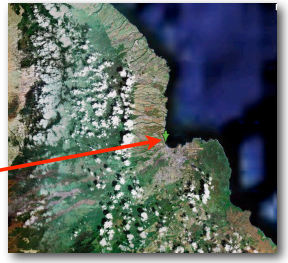
Tsunami at the Shore

- Wave slowing & shortening near shore
  - Increases height



www.globalsecurity.org/eye/andaman-pix2.htm

Tsunami at the Shore



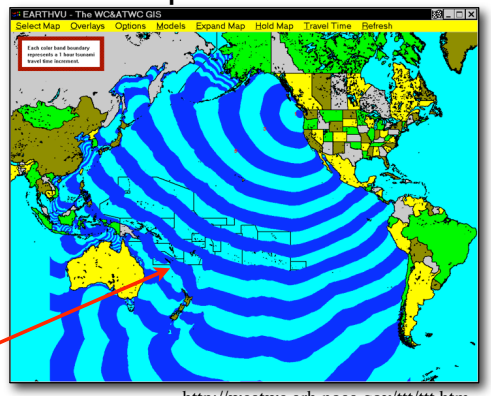
- Some waves are channeled by shape of shoreline
  - Increases height
  - Hilo, Hawaii v-shaped harbor
    - Funnels incoming waves
    - Less damage on other shores
    - 1946 Aleutian quake
      - 96 dead in Hilo, 150 total in Hawaii
      - 25 foot wave
      - Led to establishment of Pacific Tsunami Warning Network
    - 1960 Chilean quake
      - 61 drown

Tsunami at the Shore

- Steady rise in sea level
  - Patong Beach 12/26/2004
    - http://video.google.com/videoplay?docid=-1771919997701554 73&q=tsunami
  - Phuket Thailand 12/26/2004
    - http://video.google.com/videoplay?docid=-8583433486934683879&q=tsunami
  - Prolonged landward flow & powerful drainage
- NOT the huge breaker of sci-fi movies
  - Except rare cases of bay funneling
    - Koh Lanta Thailand 12/26/2004
    - http://video.google.com/videoplay?docid=-5297944181061647 93&q=tsunami
- A series of waves 5–20 min apart (period)

Tsunami Warnings

- Arrival time predictions based on known speed & depth relationship
  - Simulated quake at Neah Bay WA
    - Tip of Olympic Peninsula
  - Each colored band = 1 hour
  - Note slowing in shallow areas



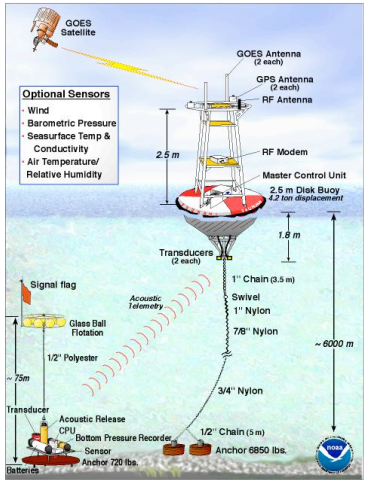
http://wcatwc.arh.noaa.gov/ttt/ttt.htm

Tsunami Detection

- Global seismometer network
  - Sense any quake within minutes
  - Triangulate to determine location epicenter
- Tidal stations
  - Detect changes is sea level along coast
  - In sequence, calculate wave speed & direction
- New Pacific tsunami sensor system (2006)
  - U.S. Nat. Oceanic & Atmospheric Admin.
    - Deep Ocean Assessment & Reporting of Tsunami
    - NOAA DART http://nctr.pmel.noaa.gov/Dart/index.html

"Tsunameter"

- DART system
  - Surface buoy detects vertical motion
    - Computer filters out shorter waves
  - Bottom instrument detects pressure waves
    - Relays data to surface
    - Buoy relays to land stations via satellite
    - Animation http://nctr.pmel.noaa.gov/Mov/DART_04.swf



http://nctr.pmel.noaa.gov/Dart/dart_ms1.html

Tsunami Detection

- "Nerve centers" in Hawaii & Alaska
  - Set up starting 1948
    - After 1946 Aleutian/Hawaiian disaster
  - Collect data from all 3 sources
    - Seismic, tide, now tsunameter
  - Predict arrival time & send warning
  - Pacific Tsunami Warning Center (Hawaii)
    - www.prh.noaa.gov/pr/ptwc/
  - West Coast & Alaska Tsunami Warning Center
    - http://wcatwc.arh.noaa.gov/

Pacific Tsunami Warning

www.globalsecurity.org/eye/andaman-pix2.htm

Tsunami Warnings

- No warning system in Indian Ocean at time of "Banda Aceh"
  - Hawaii Center predicted tsunami in real time
  - But no notification system in Indian Ocean
    - Poverty, lack of technology & education
    - Motivation?

http://epod.usra.edu/archive/epodviewer.php3?oid=226848