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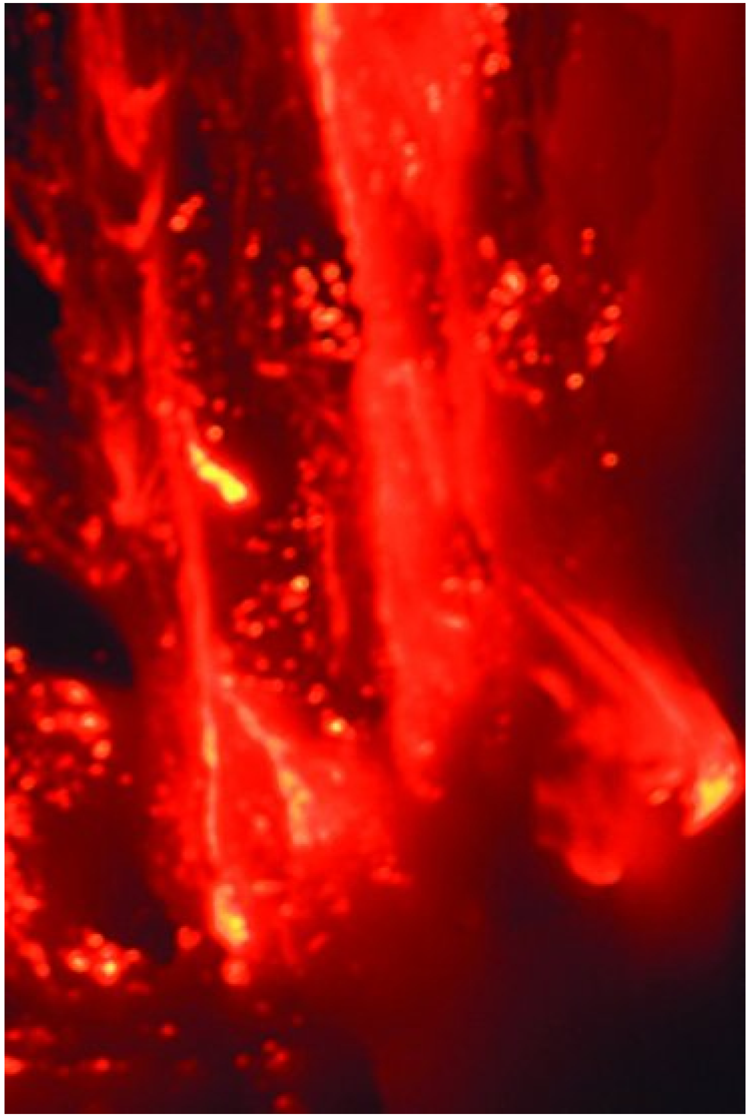

TSUNAMI: hazard, risk & damage potential

Bill McGuire

UCL

Talk plan

Sri Lanka, December 28th 2004

- What is a tsunami?
- How are tsunamis formed?
- Where do tsunamis occur?
- Tsunamis of the past
- Tsunami characteristics
- How tsunamis cause damage
- Future threats

Asian tsunami retrospective

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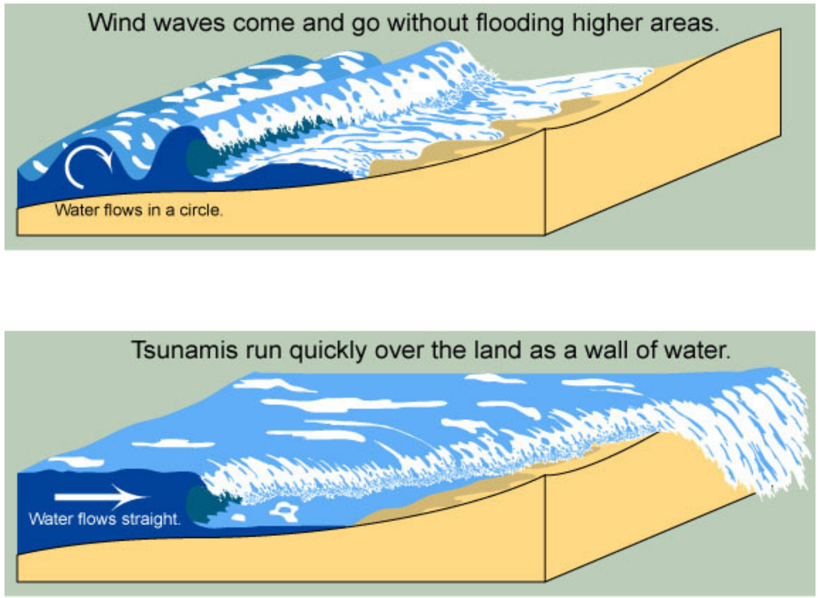
- 305,276 dead or missing
- 500,000 injured
- 1.7 million internally displaced
- 4 million impoverished
- 2 million unemployed
- 410,000 buildings destroyed
- Citizens of ~ 40 countries killed and injured

Thailand, December 26, 2004

What is a tsunami?

Tsunamis are often no taller than normal wind waves, but they are much more dangerous.



- Japanese term: ‘harbour wave’
- Anomalous water wave
- Primarily formed by submarine earthquakes
- Also:
  - volcanic eruptions, caldera collapse, volcanic landslides
  - submarine landslides
  - asteroid/comet marine impacts
  - meteorological effects

Where do tsunami occur?

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- Tsunami reported from all ocean basins
- Pacific = highest risk
  - More than 50%
- SE Asia ~ 20%
- Mediterranean ~ 10%
- Caribbean ~ 14%
- Atlantic ~ 2%
- Earliest accounts from China ~ 4000y BP, Europe ~ 2000y BP and Japan ~ 1300y BP

Lisbon earthquake 1755

Notable tsunami of history and prehistory

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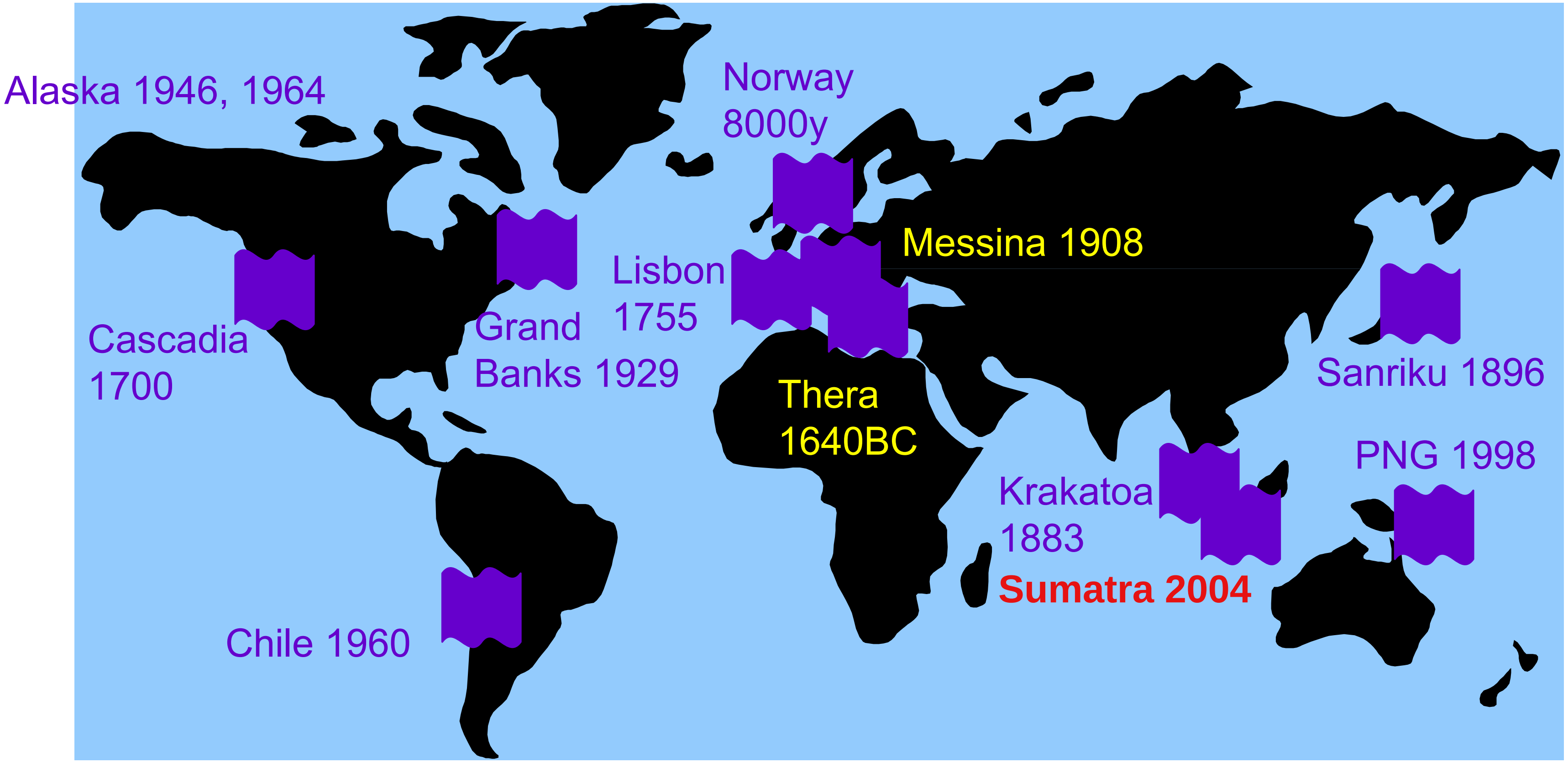

The Pacific

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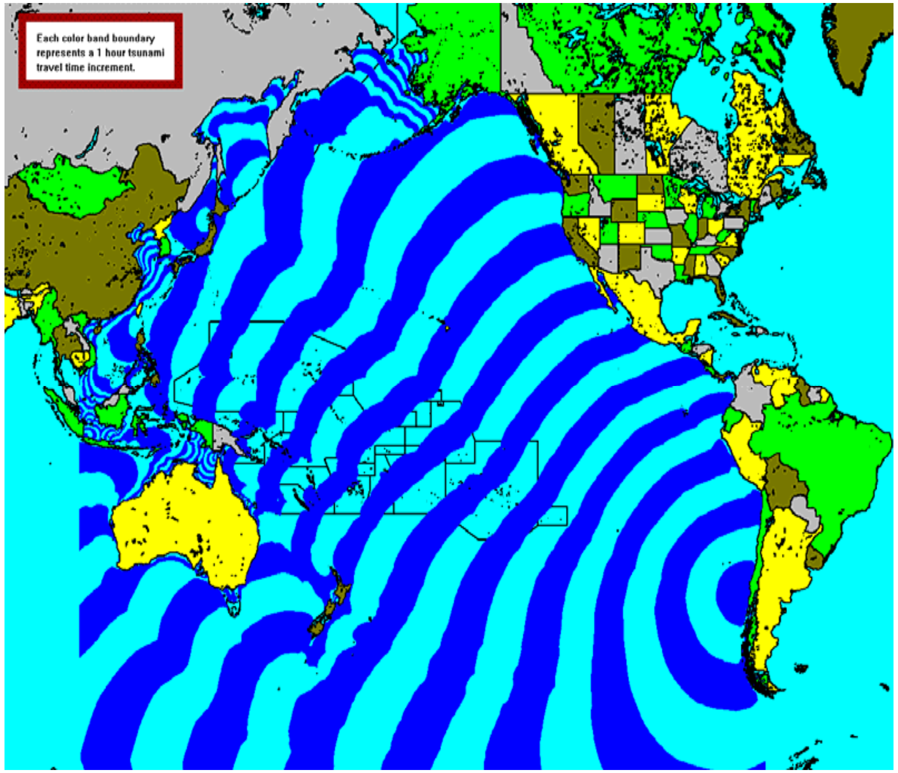
- > 1200 tsunami reported in Pacific since 47 BC
- Main sources: Alaska, Kamchatka, southern Chile
- Highest risk areas
  - Northern California
  - Hawaii
  - SW Chile and Chile-Peru border
- ~500,000 deaths in last 2000 years
- Large tsunami occur on average every 25 years
  - Chile 1960 (Japan)
  - Alaska 1964 (Crescent City, California; LA & Long Beach)



1960 Chile tsunami

The Mediterranean

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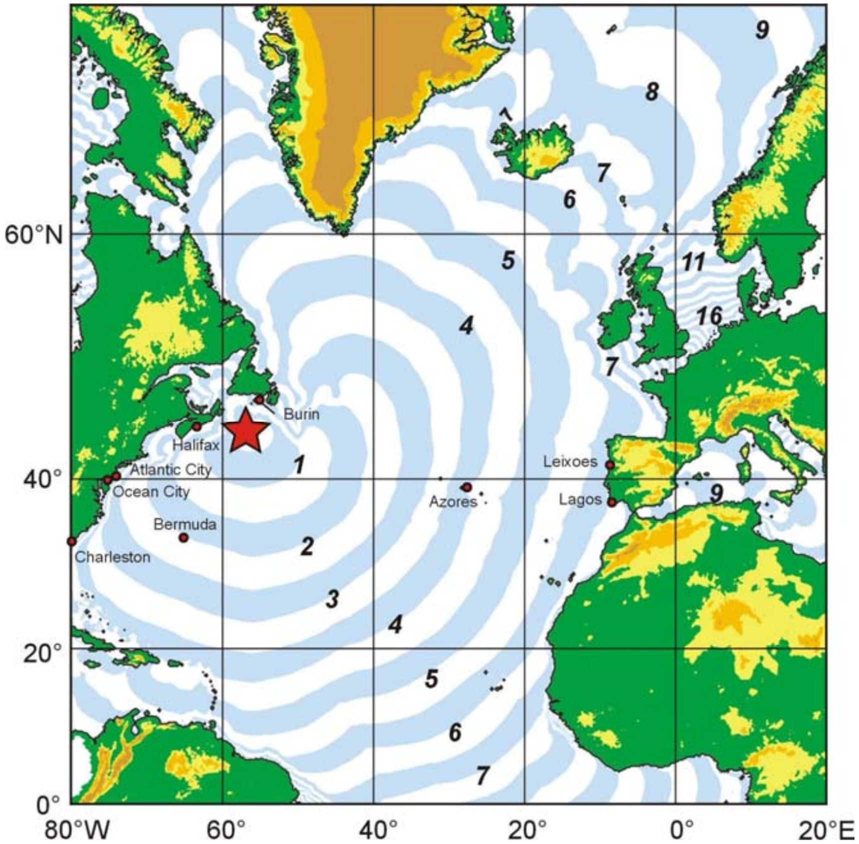
Messina (1908) tsunami damage

- 1640 BC eruption of Santorini may have resulted in 90 m tsunami
- > 300 events recorded since
- High risk areas
  - Eastern Med
  - Straits of Messina
  - off southern Portugal
- Italy ~ 67 tsunami in last 2000 years
- 1908 Messina (Italy) quake
  - Tsunami killed 8,000

The Atlantic



Grand Banks 1929

- Tsunami rare but not unknown
- LISBON quake 1755
  - 15 m high tsunami
  - destroyed port of Lisbon and struck Cadiz and Madeira
  - Damaging 7m wave recorded in Caribbean
- NEWFOUNDLAND 1929
- UK/France: Dover Straits 1580?
- UK: North Devon, Somerset & South Wales 1607?
- Storegga slide ~ 8,000y
- Shetlands ~ 5,500 + 1,500y
- Canary Island threat
- Caribbean: frequent tsunami

Tsunami characteristics

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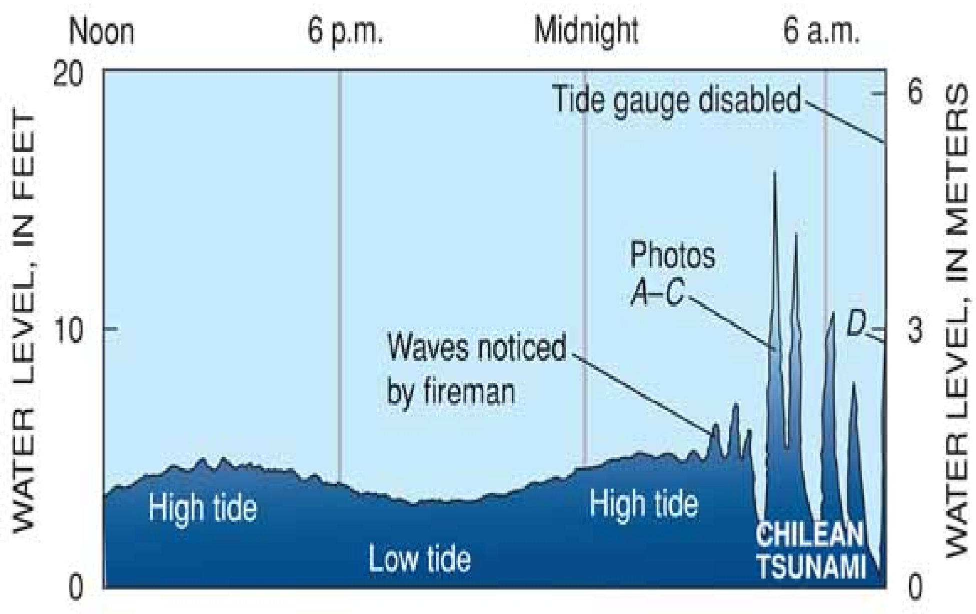
- Cross ocean basins with little loss of energy
- Involve movement of entire water column
- Speed of 800-900 km h (>500mph) in deep water
- Wavelengths of hundreds km
- Run-up heights of tens – hundreds m
- More than one wave (wave train)
- Transmit destruction to locations remote from source
  - Impact on geographically dispersed portfolios



Chile 1960 wave train recorded at Onagawa harbour, Japan

Seismogenic tsunami

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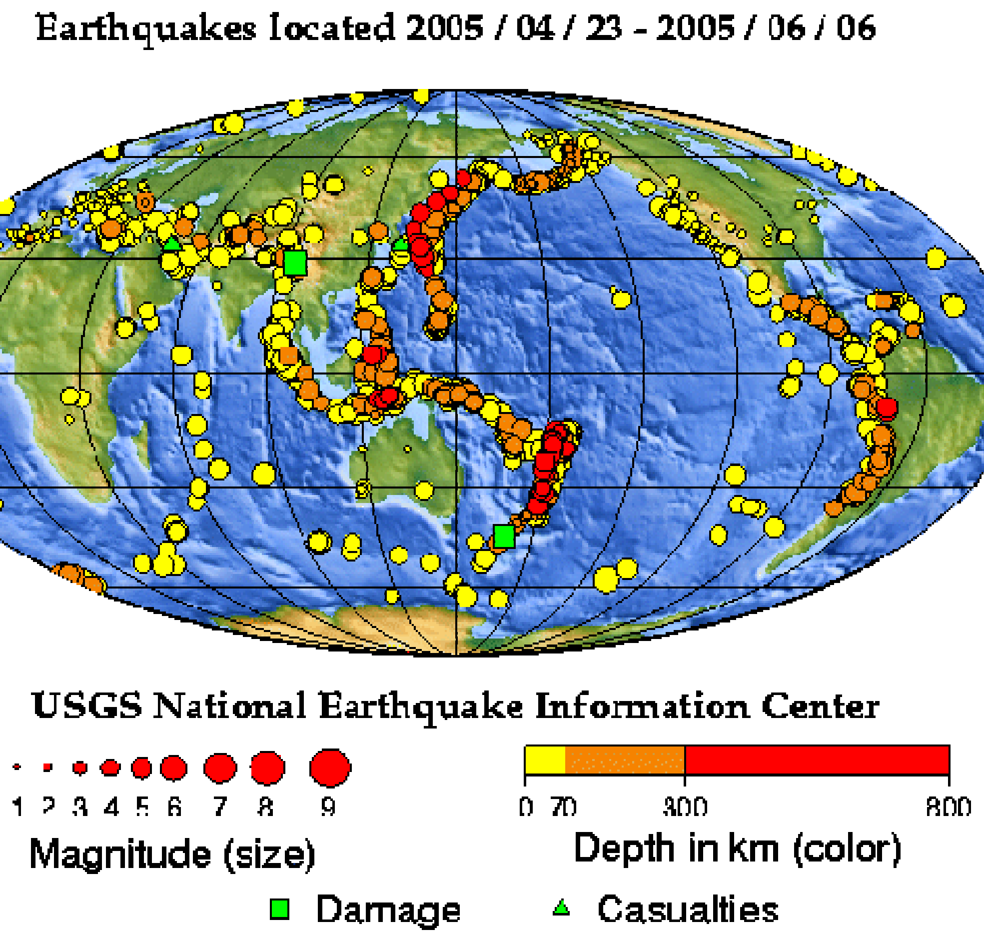
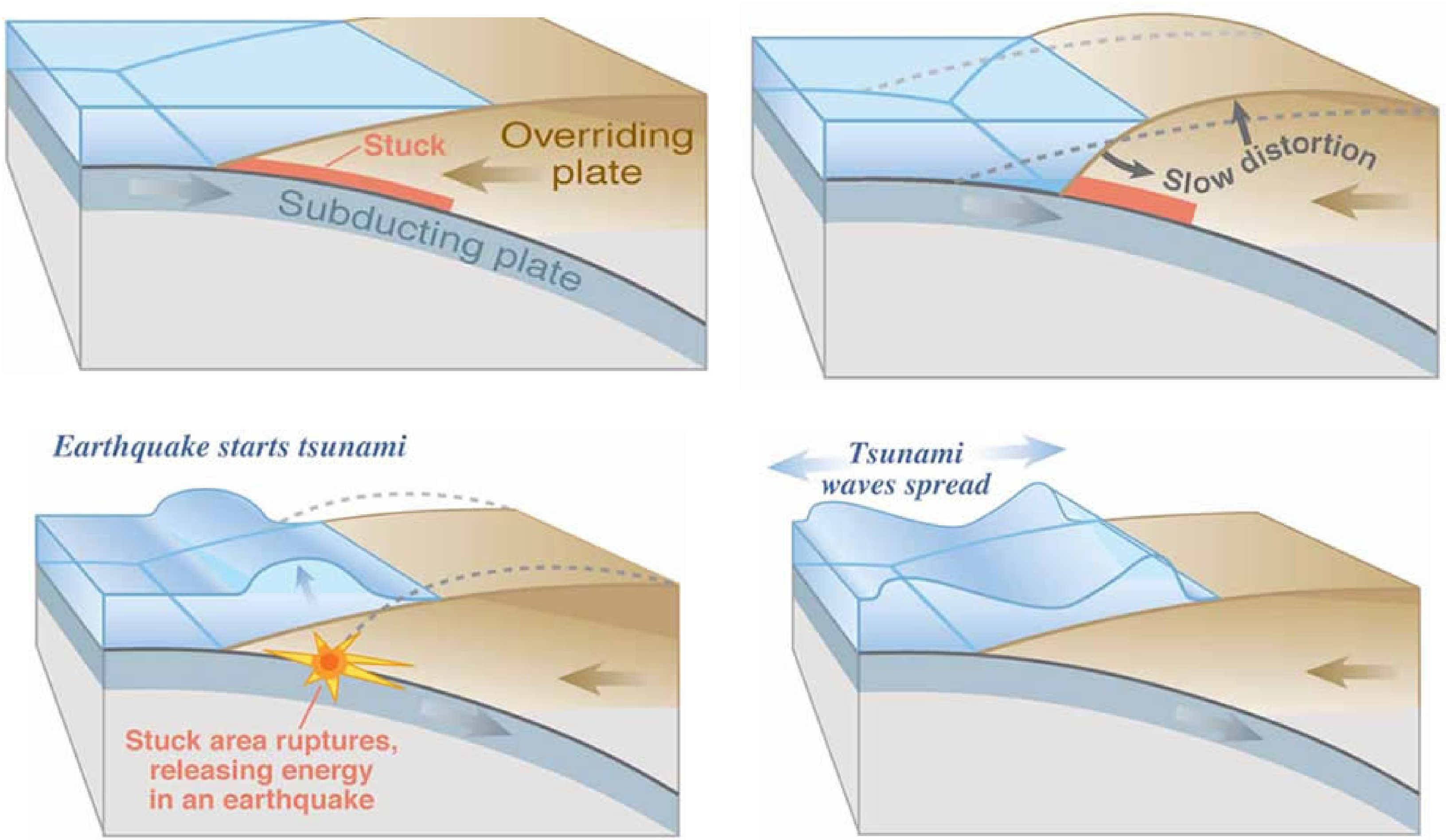


Mega-thrusts as tsunami sources



Tsunamigenic earthquakes

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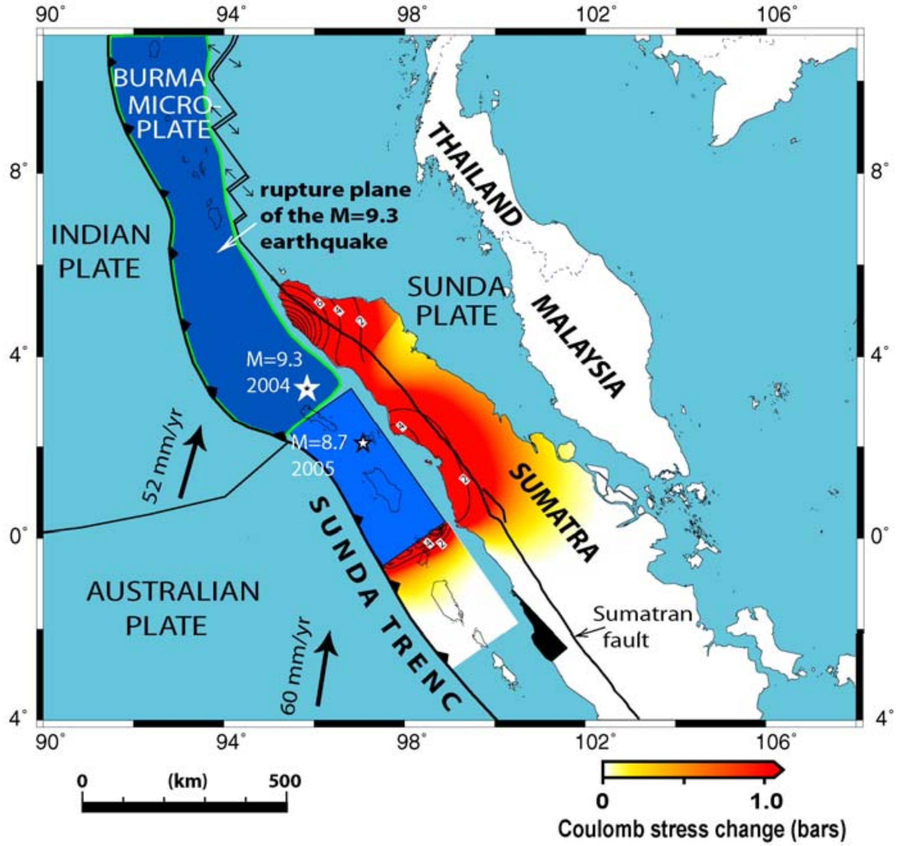
- Not all submarine earthquakes generate tsunami
- Minimum ~ Magnitude 6.5 (magnitude 8+ most effective)
- Shallow depth (< few 10s km)
- Long rupture and vertical displacement of large (hundreds of thousands km^2)
- Submarine landslides



Tsunami relationships I: velocity, wavelength and depth

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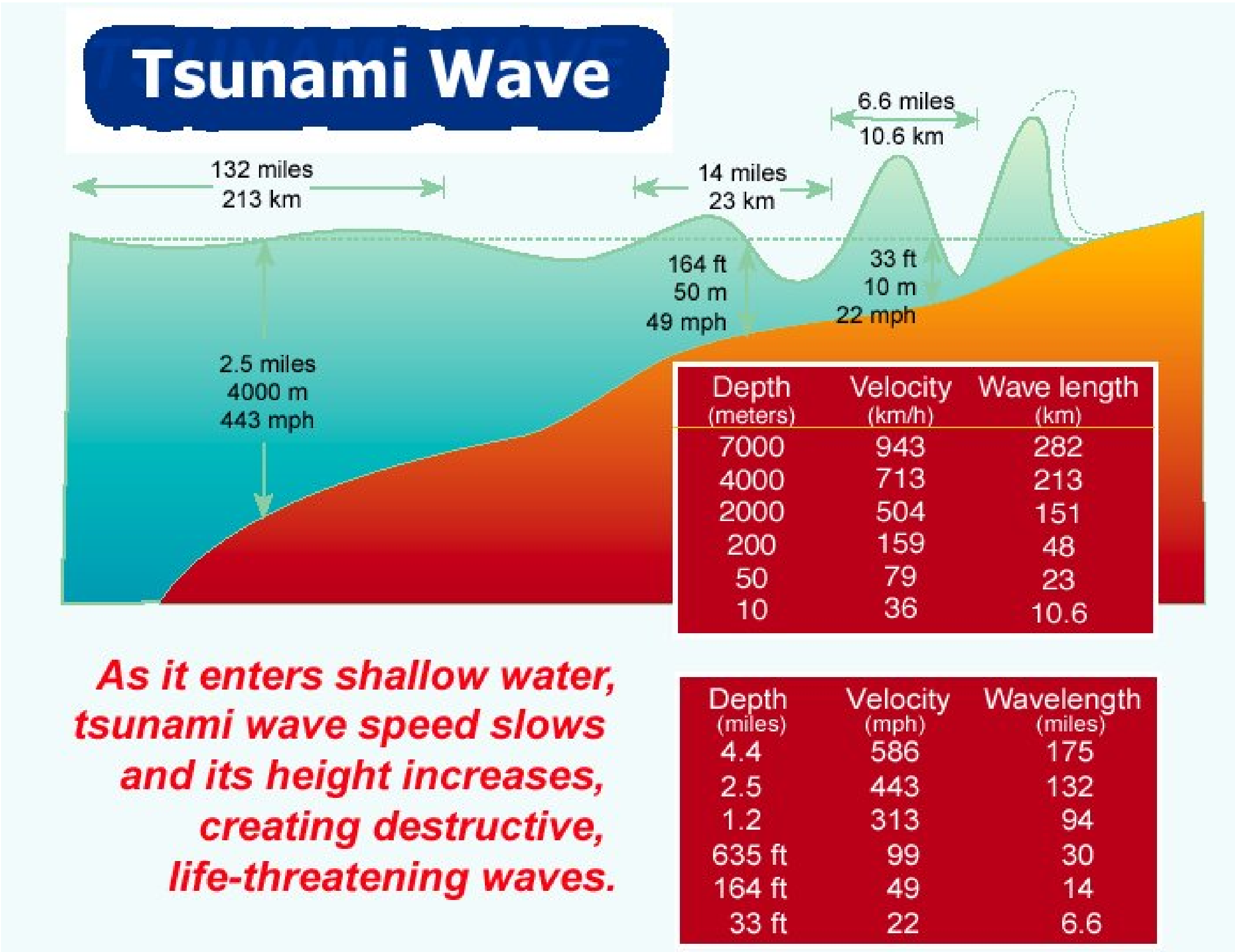

Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

Depth (miles)	Velocity (mph)	Wavelength (miles)
4.4	586	175
2.5	443	132
1.2	313	94
635 ft	99	30
164 ft	49	14
33 ft	22	6.6

Tsunami relationships II: wavelength, period and velocity

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- ***Wavelength***: crest-to-crest distance
- ***Wave period***: time taken for a single wavelength to pass a specified fixed point
- *Wavelength = wave period x wave velocity*
- Tsunami travelling with v = 800 km h and period of 0.5 h
- → wavelength of 400km
- Tsunami with wavelength of 200 km and a period of 0.5 h
- → v = 400 km h

Tsunami energy & destructive potential

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- Destructive power arises from ***wave height*** as well as velocity
- Doubling wave height will increase energy available for destruction 4 times
- Trebling height will increase energy 9 times
- ***Wavelength*** also important
- Energy of tsunami = proportional to wavelength x wave height^2
- Storm wave (m)
  - *100 x 5 x 5 = 2500*
- Tsunami (m)
  - *200,000 x 10 x 10 = 2,000,000*
- 8,000 times more energy

More on destructive potential

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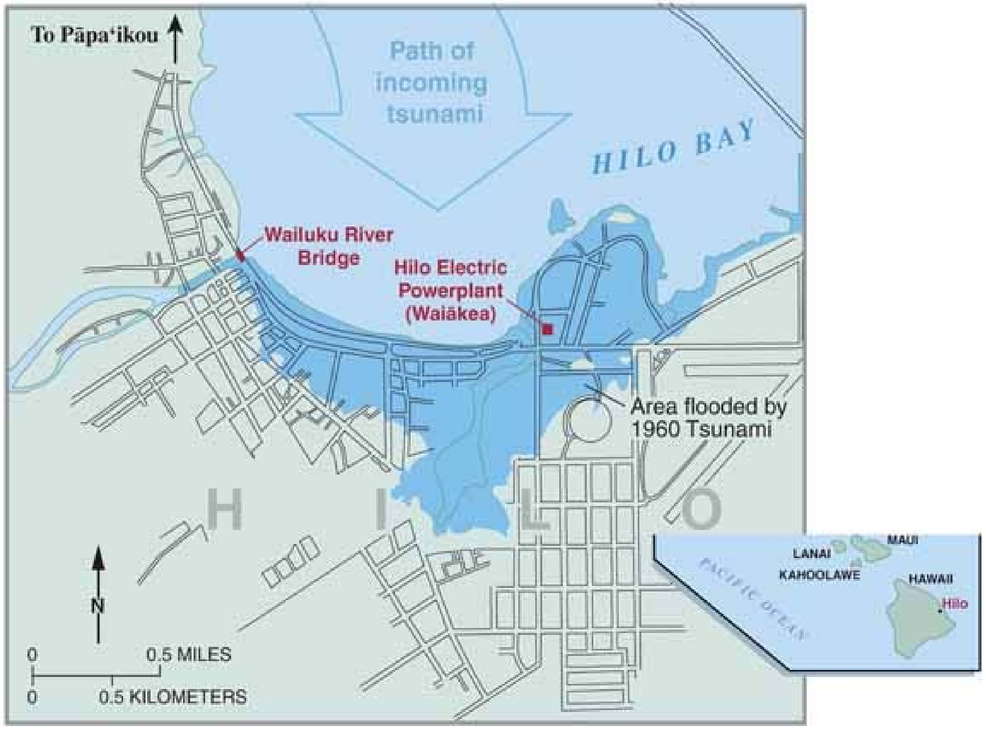
- Width of wave controls length of coastline affected (rupture length)
- Fault orientation controls direction of tsunamis (Bangladesh)
- Coastal morphology
  - focusing often occurs in bays, estuaries and harbours where resonance amplifies wave height; waves may wash back and forth for hours
  - Focusing also in lees of circular islands
- Refraction effects reinforce waves at headlands



Hilo (Hawaii) 1960

Death and injuries

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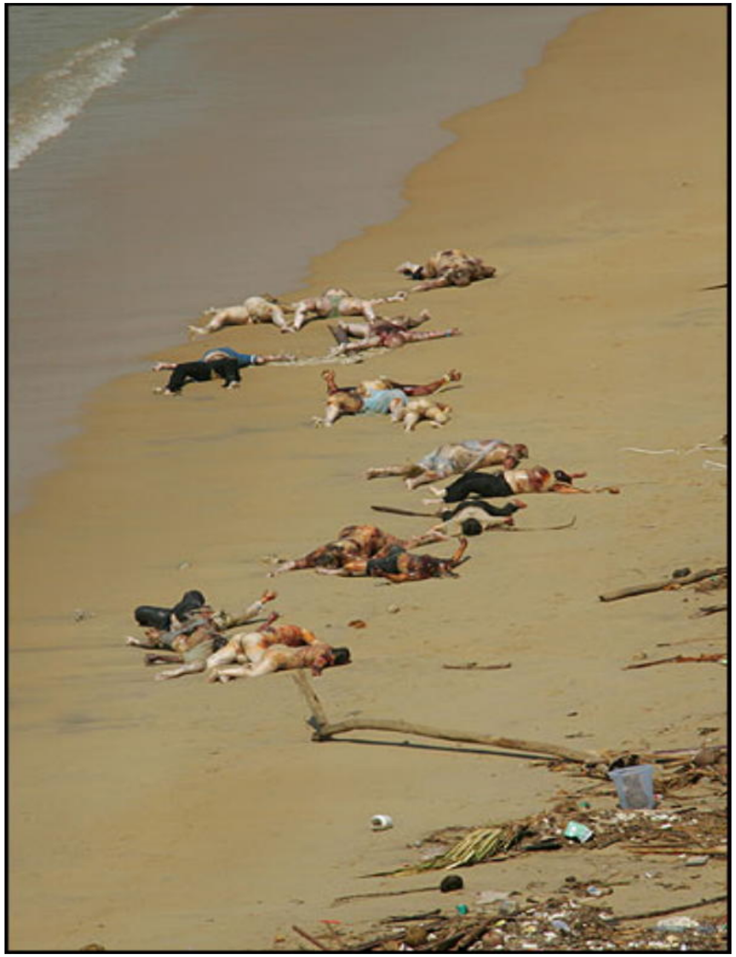
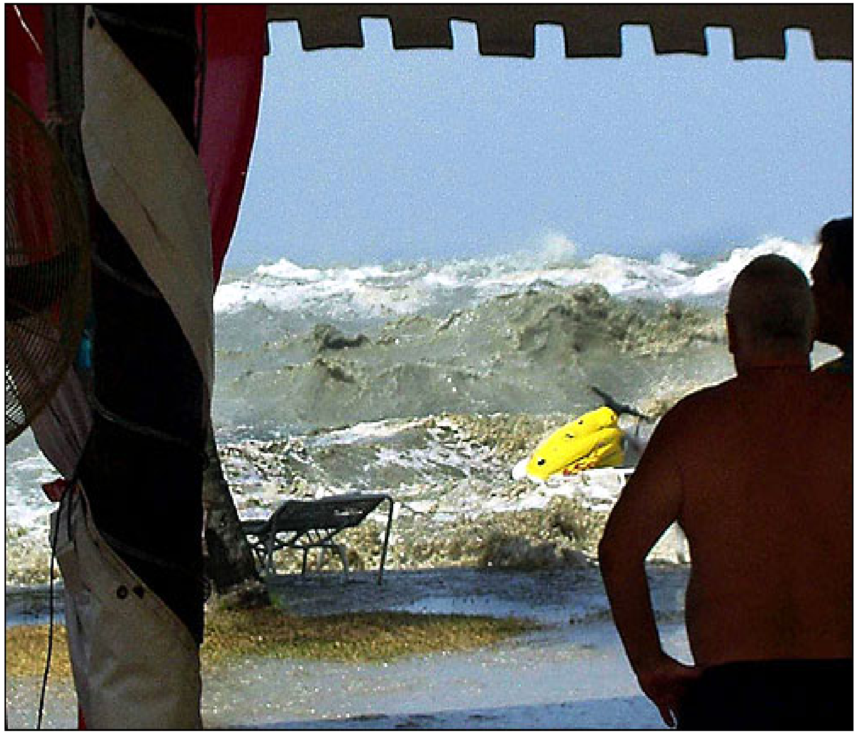


- Drowning
- Wreckage bombardment
- Sandblasting
- Carried out to sea
- Sharks
- Infection & disease
- Women, young children, old, infirm, non-swimmers especially vulnerable
- Asian tsunami ~ 100,000 children killed

Loss potential determinants

- Critical factors
  - Velocity (at shore up to 50 km h)
  - Run-up height (max ~ 30 m in Sumatra)
  - Inundation (max ~ 7km in Sumatra)
  - Persistence (single wave flow 10 – 30 min; followed by ebb)



Asian tsunami: Panang (Thailand)

Tsunami damage: inundation

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Banda Aceh (2004)

- Terrain topography
- Surface roughness
- May exceed 10 km
- Flood damage
- Floatation & drag forces
  - move buildings
  - overturn trains
  - carry ships (up to kms) inland
- Floating debris forms projectiles
  - Damage buildings
  - Bring down power lines
  - Start fires
- Tsunami draw-down → uncover nuclear power plant cooling water intakes

Wave impact and erosive effects

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- Ports & coastal installations in front line
- Force of impact (plus debris)
  - Total destruction of wood and most brick buildings
  - Destruction or severe damage to well constructed (steel-reinforced concrete and masonry) buildings
  - Rupturing of coastal oil storage tanks and refinery facilities → fires
- Strong currents
  - Erosion of foundations
  - Collapse of bridges and sea walls
- Offshore hydrocarbon exploration and production platforms unaffected

Hawaii 1960

Banda Aceh:June 23rd 2004

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Banda Aceh: December 28th 2004

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Asian tsunami: Thailand waterfront damage

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- Water depth of 3-4 m sufficient to obliterate many waterfront properties
- Extensive damage or destruction of masonry or RC structures
- Columns with substantial steel reinforcing failed at ground level
- Erosion of ground surface and paved surfaces down to several metres → building failure
- Sea-water immersion of steel building frames, reinforcing steel and other components likely to be problem in standing buildings
- Large boats washed more than a kilometre inshore

Damage to lightly reinforced concrete house

Thailand: more damage

Ground scour causing building failure

Infill panel failure in RC frame structure

Thailand: more

Extensive damage to RC building

Debris clogged streets

Thailand & Sri Lanka

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Police launch washed 1.2 km inshore

Masonry building (Galle, Sri Lanka)

Aceh (Indonesia) & Thailand

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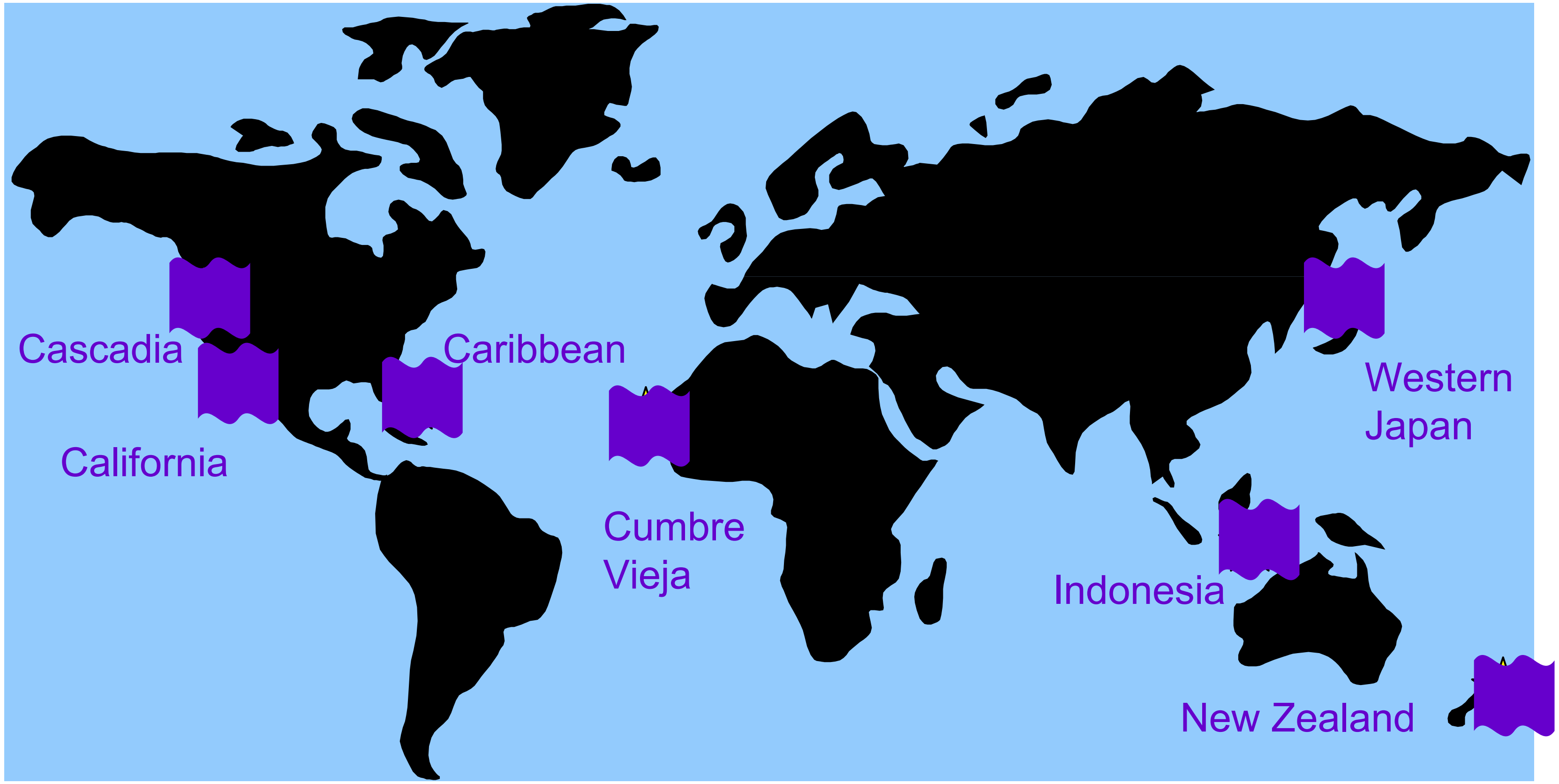
Identified future tsunami risk



The coming Cascadia mega-thrust quake and Pacific tsunami

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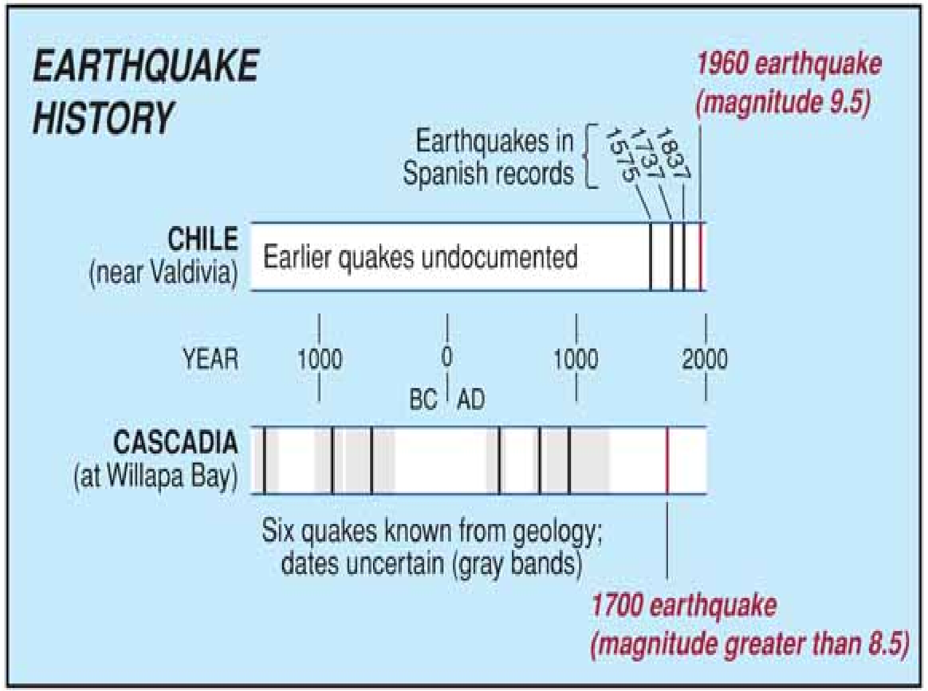
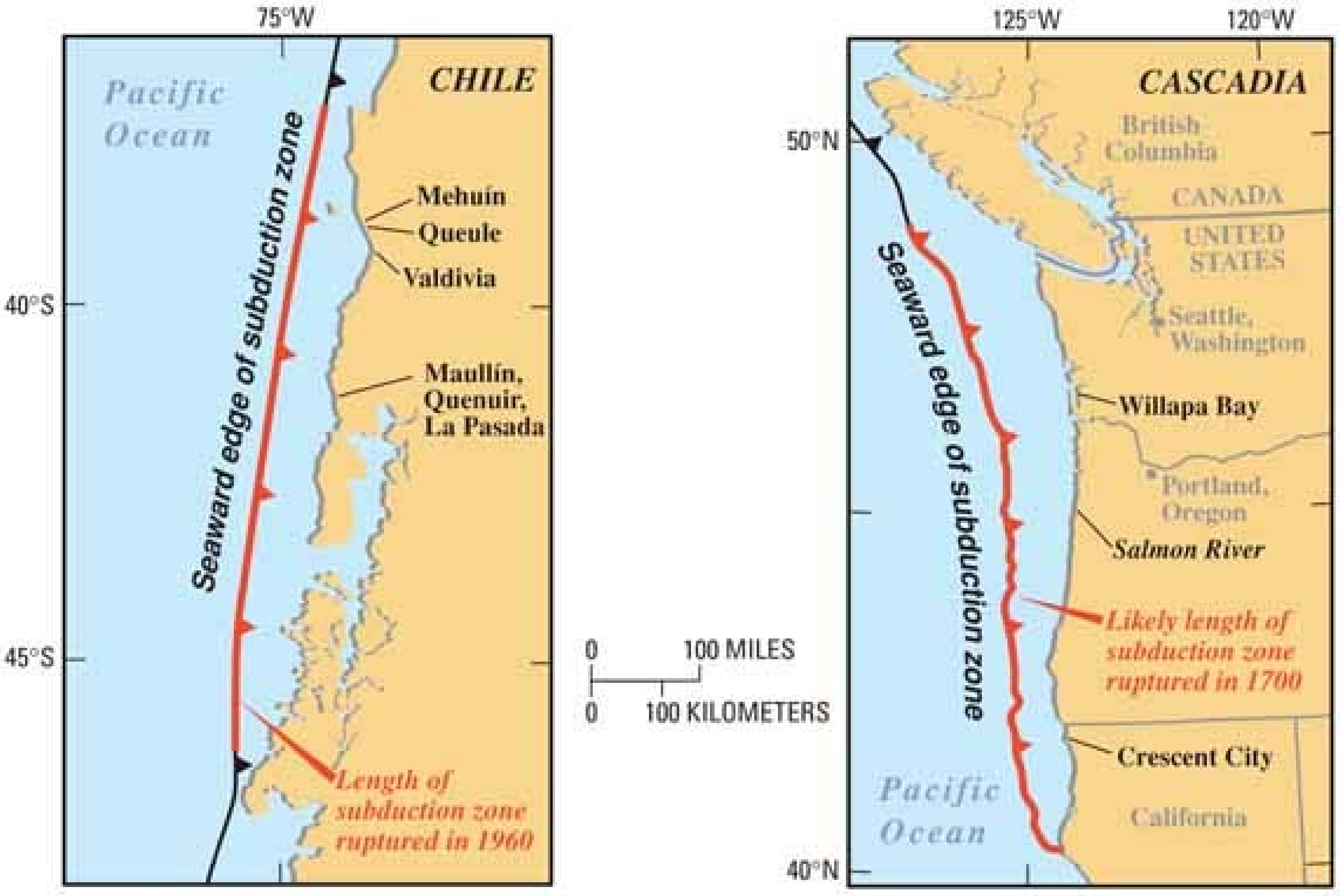
- 1700AD: Magnitude 9 earthquake in Cascadia subduction zone
- 1100km rupture zone
- 10m tsunami in southern Canada, Washington, Oregon and northern California
- Arrival 15-40 min after quake
- 3m tsunami in Japan
- Return period ~ 500 y
- Subduction zone locked



Cascadia and Chile subduction zones compared



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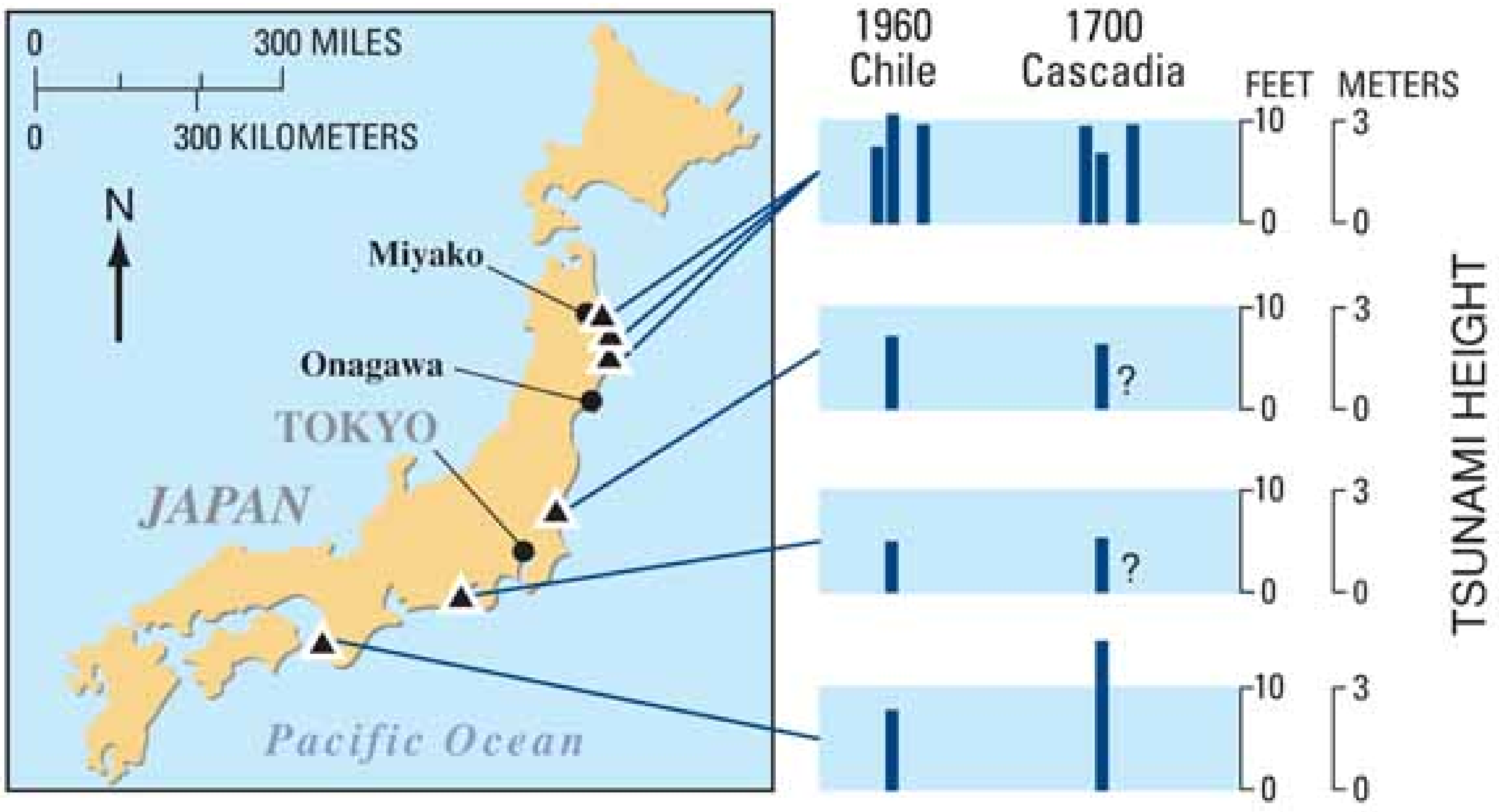
The 1700AD Cascadia tsunami record in Japan



Major tsunami threat in the Atlantic Basin

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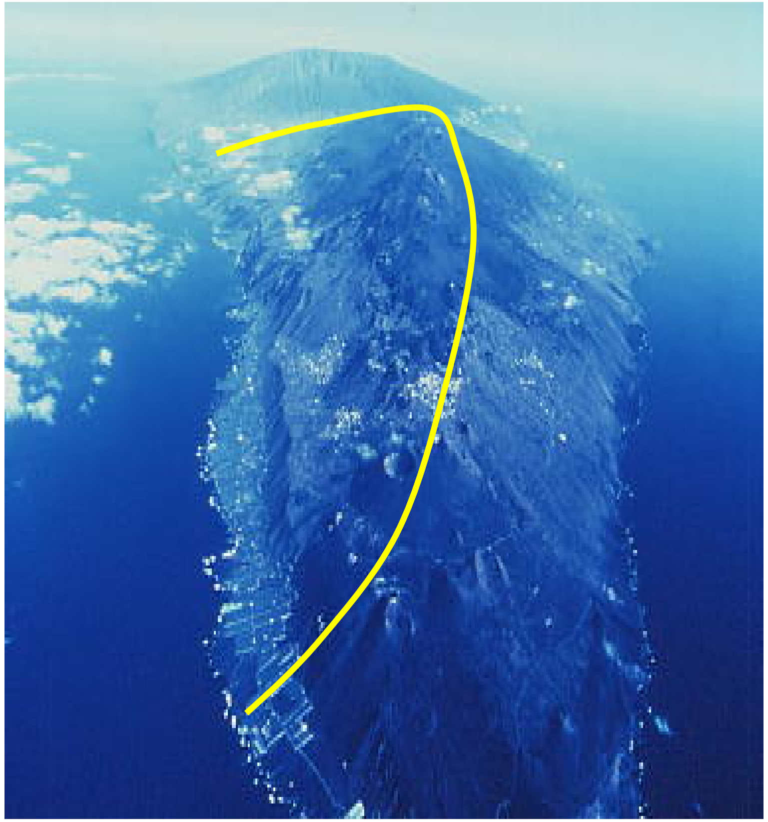
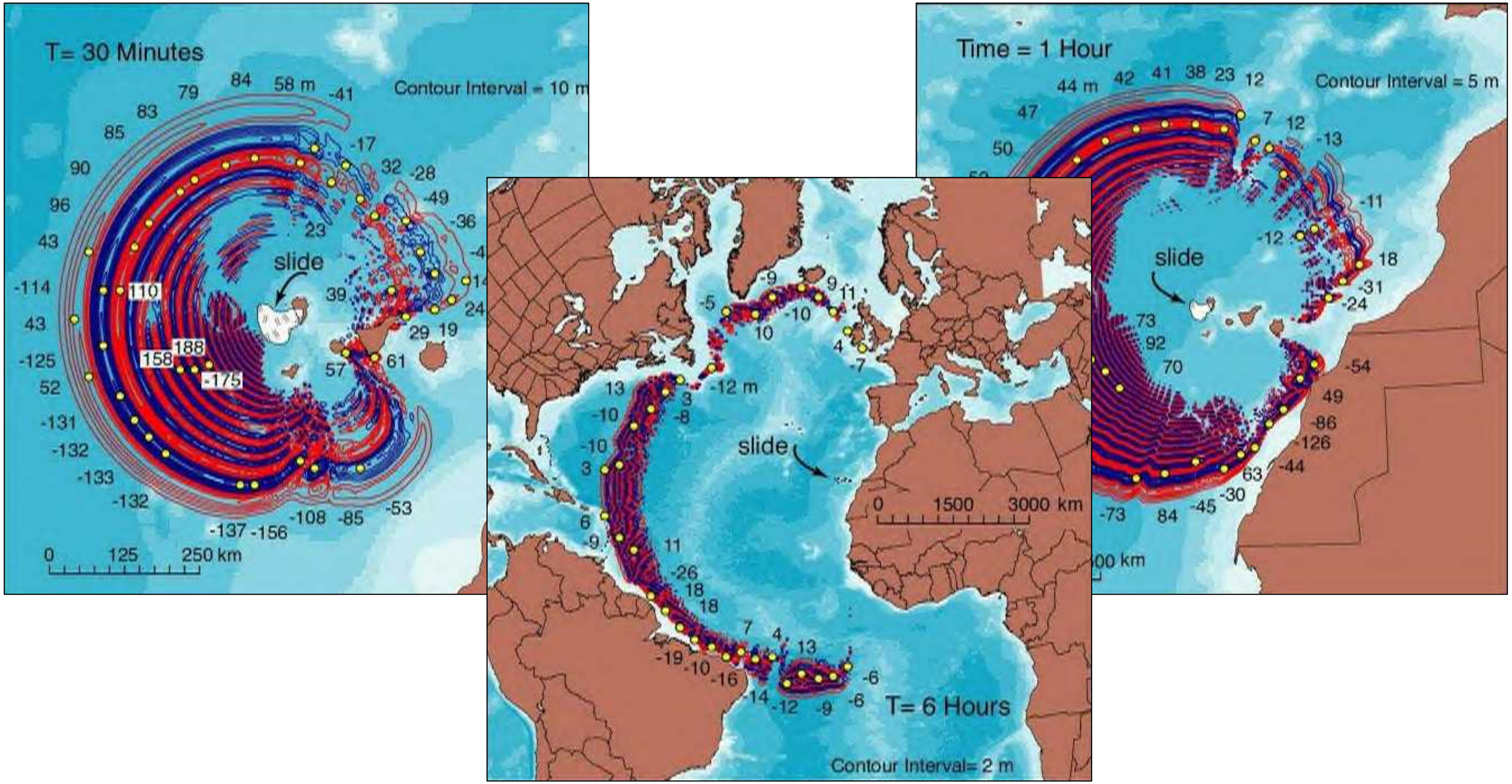


Cumbre Vieja volcano (La Palma)

- Up to 500km^3 of west flank detached and unstable
- Dropped 4m during eruption in 1949
- Moving ~ 1cm y?
- Future collapse will be catastrophic
- Timing: future eruption. Frequency – 20 to 200 y
- Major tsunami threat to Atlantic rim

The resulting tsunami



Summary: general

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Alaska 1964

- Tsunamis: greatest destructive reach of any natural hazard
- Potential for complete destruction of, or severe damage to, port and waterfront facilities and shipping in dock
- Frequency of major basin-wide tsunami is only ~ 20-25 years
- Local, damaging tsunami annually
- Exposure ↑ rapidly due to increasing construction and wealth concentration in coastal zones
- Clear threats to Atlantic rim, Pacific coast of North America, Japan and the Caribbean
- Situation exacerbated by climate change triggered sea-level rise

Summary 2: specific

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- The front line: maximum exposure
- Wood and brick constructions most vulnerable; stone, steel and concrete structures may also fail/suffer serious damage
- Focusing effects increase risk in otherwise protected bays, harbours and estuaries
- Ships and boats safest offshore; least safe in marina, harbour or in dock (relevance of new warning systems)
- Serious risk to chemical plants, refineries, fuel storage facilities and nuclear power generation plants

DART Mooring System