Measuring Earthquakes

Two measurements that describe the "power" or "strength" of an earthquake are:

- **Intensity – a measure of the degree of earthquake shaking at a given locale based on the amount of damage.**
- **Magnitude – estimates the amount of energy released at the source of the earthquake:**
  - **Logarithmic scale (not linear!)**
  - **Magnitude 2 or lower earthquakes cannot be felt by humans.**
  - **Magnitude 7 and over potentially cause serious damage over larger areas, depending on their depth.**
  - **The largest earthquakes in historic times have been of magnitude slightly over 9, although there is no limit to the possible magnitude.**

Modified Mercalli Scale vs. Richter Scale

Intensity category	Effects	Magnitude scale
I. Instrumental	Not felt	1-2
II. Just perceptible	Felt by only a few people, especially on upper floors of tall buildings	3
III. Slight	Felt by people lying down, seated on a hard surface, or in the upper stories of tall buildings	3.5
IV. Perceptible	Felt indoors by many, by few outside; dishes and windows rattle	4
V. Rather strong	Generally felt by everyone; sleeping people may be awakened	4.5
VI. Strong	Trees sway, chandeliers swing, bells ring, some damage from falling objects	5
VII. Very strong	General alarm; walls and plaster crack	5.5
VIII. Destructive	Felt in moving vehicles; chimneys collapse; poorly constructed buildings seriously damaged	6
IX. Ruinous	Some houses collapse; pipes break	6.5
X. Disastrous	Obvious ground cracks; railroad tracks bent; some landslides on steep hillsides	7
XI. Very disastrous	Few buildings survive; bridges damaged or destroyed; all services interrupted (electrical, water, sewage, railroad); severe landslides	7.5
XII. Catastrophic	Total destruction; objects thrown into the air; river courses and topography altered	8 +

Earthquake Magnitude and Energy Equivalence

Earthquake Magnitude	Energy Released* (Millions of Ergs)	Approximate Energy Equivalence
0	630,000	1 pound of explosives
1	20,000,000	
2	630,000,000	Energy of lightning bolt
3	20,000,000,000	
4	630,000,000,000	1000 pounds of explosives
5	20,000,000,000,000	
6	630,000,000,000,000	1946 Bikini atomic bomb test 1994 Northridge Earthquake
7	20,000,000,000,000,000	1989 Loma Prieta Earthquake
8	630,000,000,000,000,000	1906 San Francisco Earthquake 1980 Eruption of Mount St. Helens
9	20,000,000,000,000,000,000	1964 Alaskan Earthquake 1960 Chilean Earthquake
10	630,000,000,000,000,000,000	Annual U.S. energy consumption

barely felt

One unit of magnitude increase corresponds to ~10-fold increase in wave amplitude and ~30-fold energy increase.

Greatest Earthquakes Ever Recorded

1. (M 9.5) 22 May 1960 – Great Chilean Earthquake, Valdivia, Chile:

most powerful earthquake ever recorded; lasted ~10 min; triggered tsunami which reached Hawaii and Japan; 3000-5000 dead.

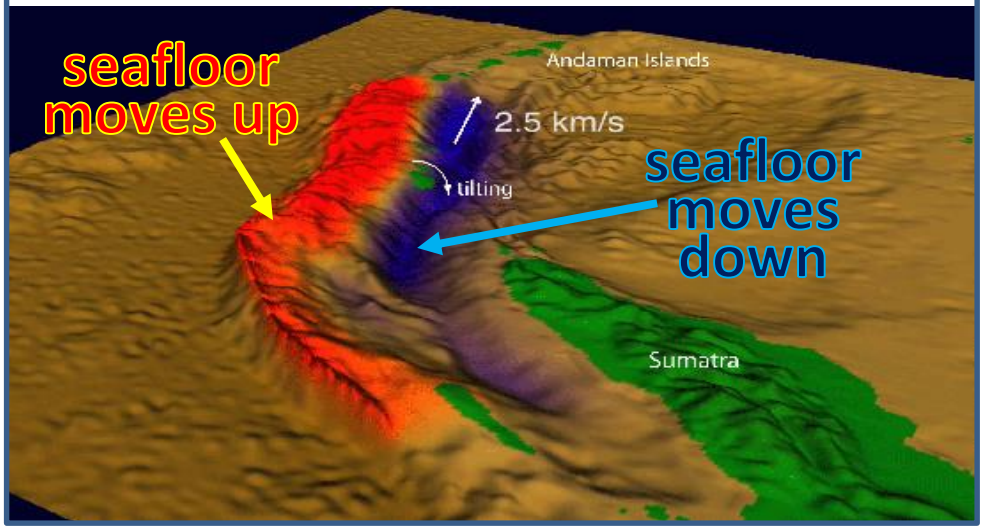
2. (M 9.2) 27 March 1964 – Great Alaskan Earthquake (aka Good Friday earthquake), Prince William Sound, AK:

lasted ~4.5 min; tsunami, soil liquefaction; 128 dead.

Greatest Earthquakes Ever Recorded

3. (M 9.1-9.3) 26 December 2004 – Indian Ocean Earthquake (aka Sumatra-Andaman earthquake), off the west coast of Sumatra:

shaking lasted ~8 min; surface wave oscillations exceeded 1 cm everywhere on Earth; the longest ever fault rupture of 1600 km triggered tsunami waves (up to 30 m high reaching as far as 2 km inland in Indonesia); killed 230,000 people in 14 countries.



4. (M 9.0) 11 March 2011 – Great East Japan Earthquake (aka Tohoku earthquake), off the west coast of Japan:

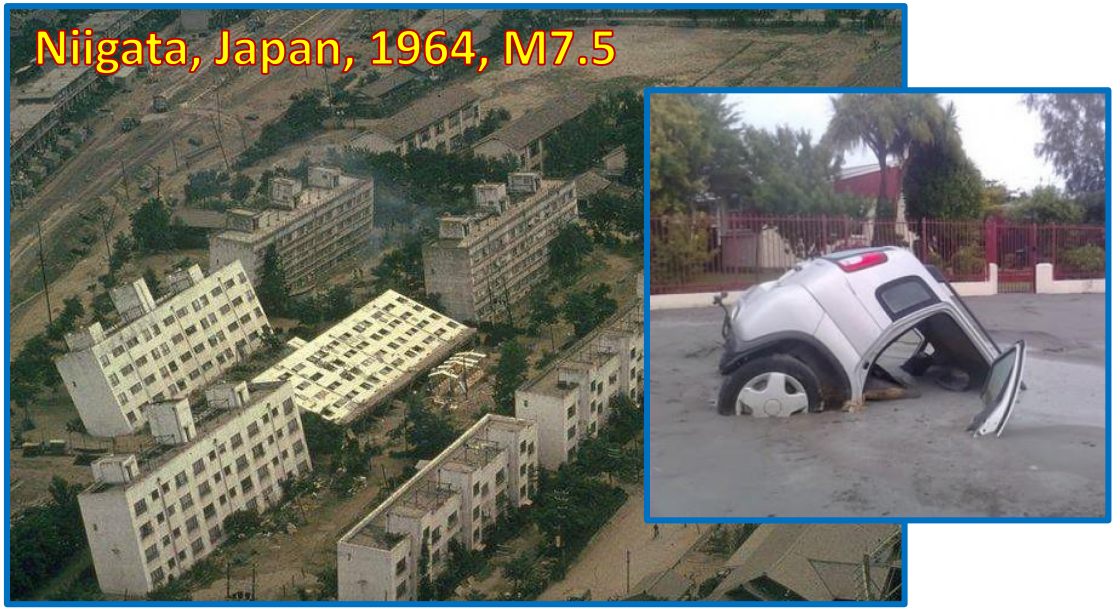
lasted ~6 min; tsunami waves (up to 40 m high, travelled as far as 10 km inland); the disaster caused partial meltdown at Fukushima Daiichi Nuclear Power Plant; 15,800 dead.

Earthquake Hazards: Shaking

Amount of structural damage due to earthquake vibrations strongly depends on intensity and duration of the vibrations. Buildings respond differently to shaking based on construction styles and materials (wood - more flexible, holds up well; earthen materials - very vulnerable to shaking).

- **High frequency body waves shake low buildings more.**
- **Low frequency surface waves shake high buildings more.**
- **Intensity of shaking also depends on type of subsurface material.**
- **Unconsolidated materials (sand, mud) amplify shaking more than rocks do.**
- **Fine-grained, sensitive materials can lose strength and collapse when shaken.**

Earthquake Hazards: Soil



Liquefaction of the ground:

- **Unconsolidated materials (*such as sand and silt*) saturated with water turn into a mobile fluid.**
- **Damage to foundation as well as sinking and tilting of structures can occur.**

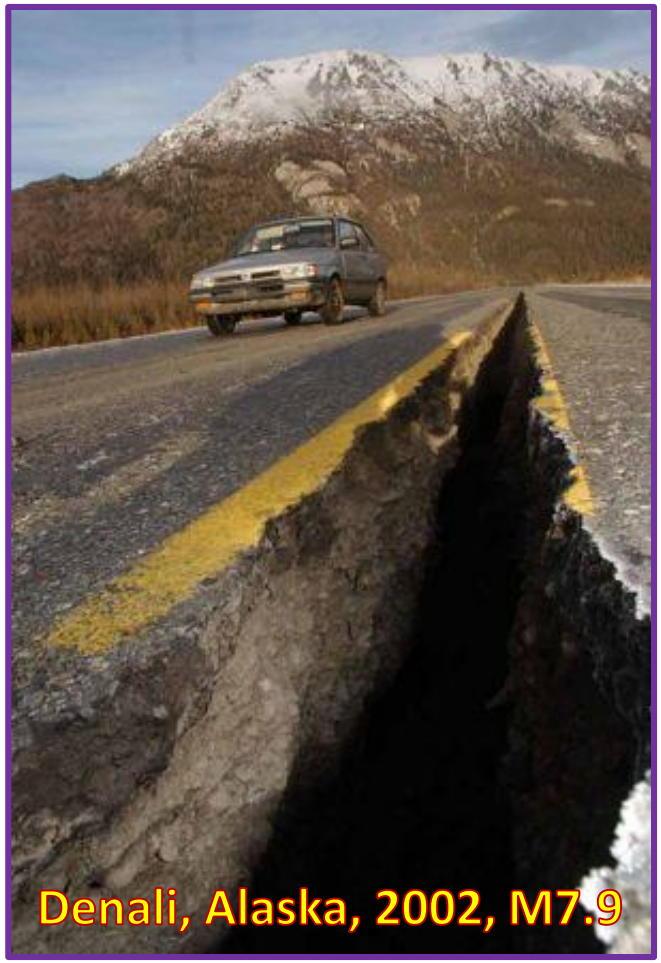
Landslides:

- **Earthquakes can produce slope instability leading to landslides.**

Earthquake Hazards: Shift

Ground displacement/rupture:

- **Ground surface may shift and split apart, especially if the focus of the earthquake is shallow.**
- **Vertical displacements of surface produce fault scarps.**



Thrust fault scarp: Chi Chi earthquake, Taiwan, 1999, M7.6

Fires: As a result of ground displacement, fires can occur from shifting of subsurface utilities (electric and gas lines).

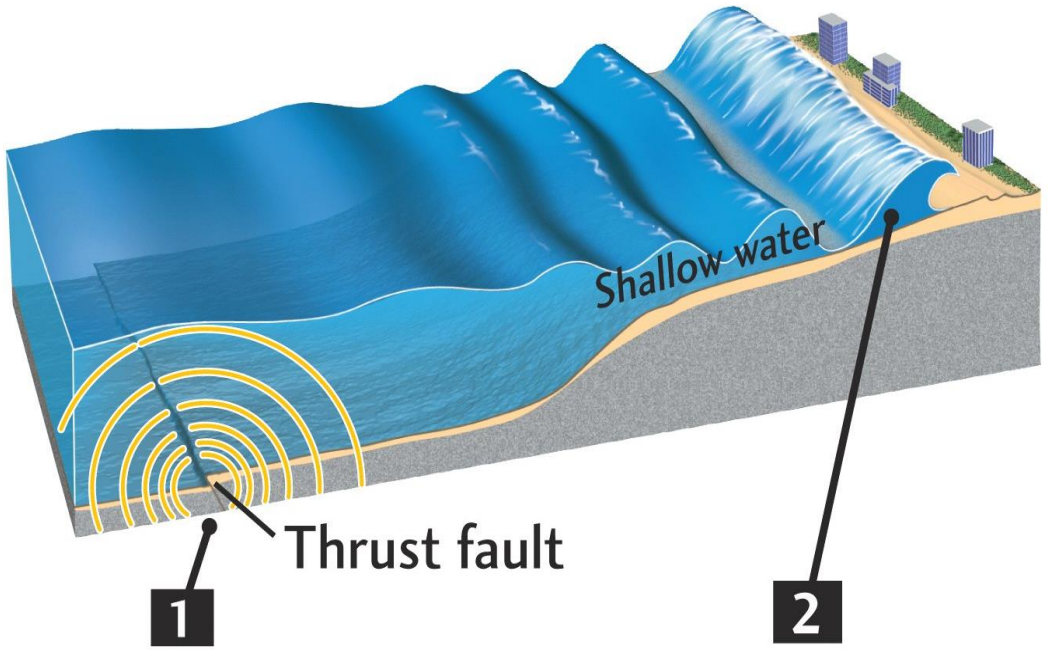
Earthquake Hazards: Water Bodies

Seiches:

- The **rhythmic back-and-forth sloshing of water** in lakes, reservoirs, and enclosed basins. Such waves **can weaken reservoir walls and cause destruction**.

Tsunami: Japanese for "harbor wave" – harmless until it enters the harbor...

1. Destructive **seismic sea waves** that result from **vertical displacement of the ocean floor** or a **large undersea landslide** triggered by an earthquake.
2. In shallow coastal waters can occasionally **exceed 30 meters** (100 feet).



Hazards and Risks of Tsunami

Tsunamis are most devastating near the earthquake.
They are larger and strike the region soon after the earthquake.

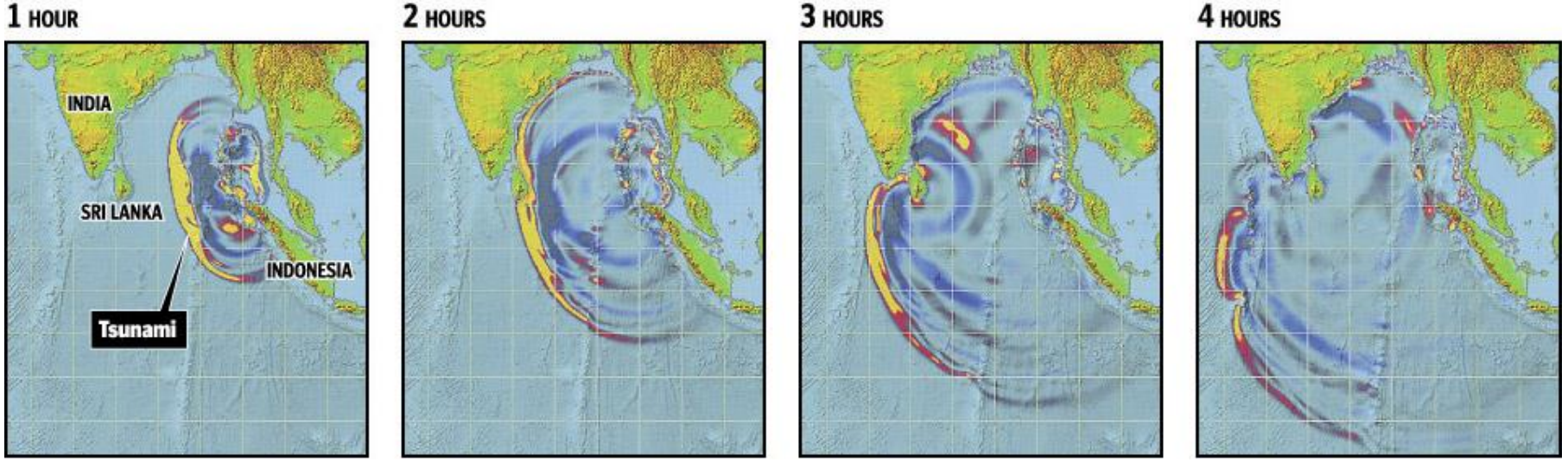
- **Tsunamis also travel across entire oceans and cause damage and death thousands of miles from the earthquake.**
- **Tsunamis travel very quickly relative to normal ocean waves, especially in open water, where velocities increase with water depth and can reach 1,000 km/hr (normal ocean wave: ~90 km/hr)**

- **The most tsunami prone areas are those associated with volcanoes and earthquakes, mainly subduction zones. Large subduction zones produce the most tsunamis: Pacific ~80%, Atlantic ~10%, elsewhere ~10%.**

Tsunami: 2004 Indian Ocean Earthquake

This giant 9.1 magnitude earthquake ruptured the greatest fault length of any recorded earthquake, spanning a distance of 990 miles (1600 km), or *longer than the state of California*.

- **Such a giant push of water generated a series of *ocean-wide* tsunami waves, the first of which hit Indonesia 25 minutes after the start of the quake.**



- **The waves had grown to 100 feet (30 m) high in some places; more tsunami waves struck Thailand two hours later, and other countries across the Indian Ocean were hit a few hours later.**

BANDA ACEH, INDONESIA: June 23, 2004
A satellite image of the waterfront area of Aceh province's capital city before the tsunami.

BANDA ACEH, INDONESIA: December 28, 2004
An image taken after the tsunami shows destroyed housing and the shoreline nearly wiped out.

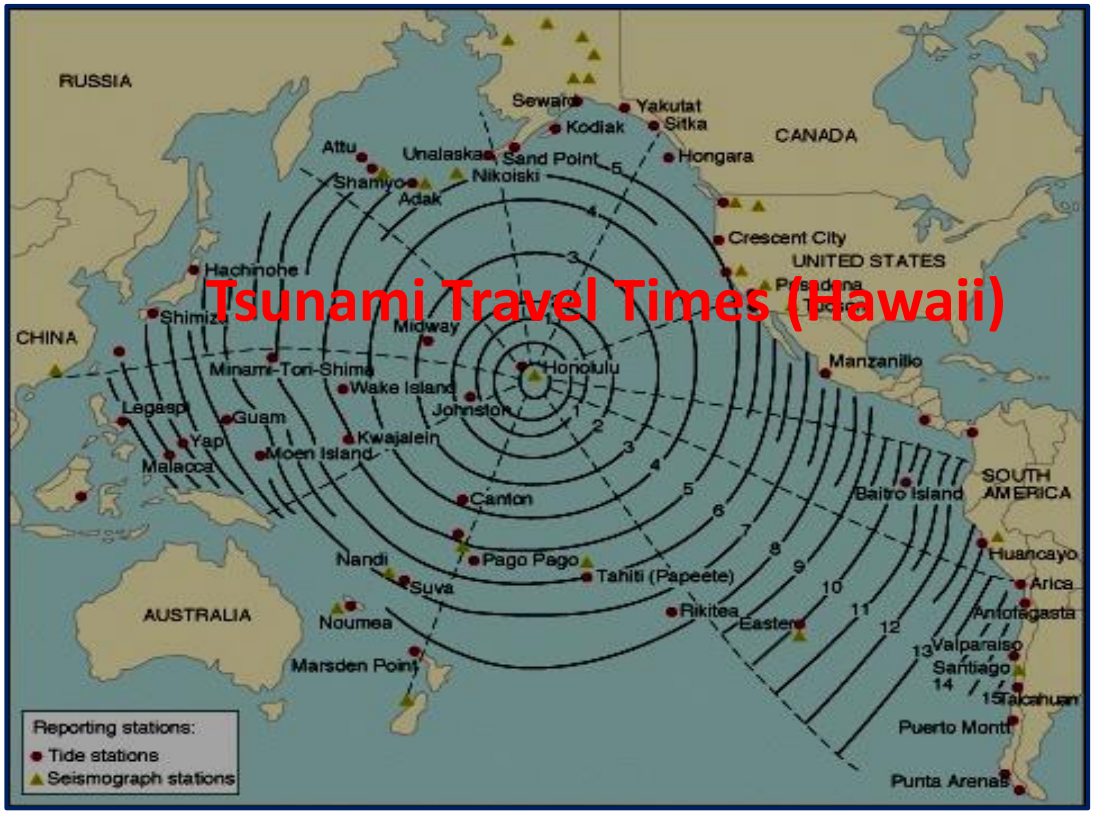
And after the water is gone…

Tsunami Warning

Regions with a high tsunami risk typically use tsunami warning systems to warn the population before the wave reaches land:

- **The Pacific Tsunami Warning System is based in Honolulu, Hawaii. It monitors Pacific Ocean seismic activity.**

- **As soon as an earthquake of magnitude >6.5 is located in the sea, the alarm starts.**
- **Using computer simulations based on real-time data from bottom pressure sensors, attached to buoys, scientists forecast the time of tsunami arrival in different locations.**

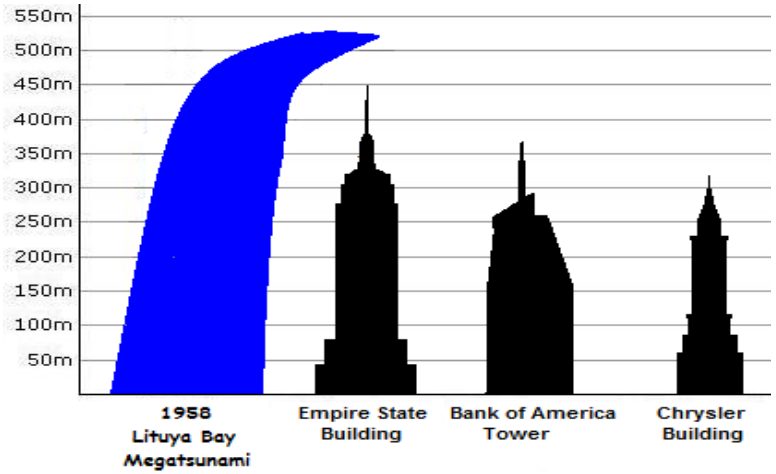


Megatsunami

Megatsunami is an informal term to describe a tsunami that has **initial wave heights much larger than normal** tsunamis.

- **Origin**: a large scale landslide, collision, or volcanic eruption event as opposed to raising or lowering of the sea floor due to tectonic activity.
- **Prehistoric**: asteroid impacts; Mt. Etna volcanic landslide; East Molokai Volcano collapse; etc.
- **Modern**: 1792, Mount Unzen, Japan (100m); 1963, Vajont Dam, Italy (250m); 1980, Mount St. Helens-Spirit Lake, WA (260m).

- **1958, Lituya Bay Megatsunami**: a huge landslide (~40 million cubic meters of rock and ice) triggered by an 8.3 magnitude earthquake in Alaska created waves with a ***run-up up to ~525m high*** *on the Lituya Bay*, **largest known in modern times**.



Future concerns: potential massive landslide on a volcanic ocean island (ex. Cape Verde, Canary Islands, Hawaii)