We have previously looked at artificial seismograms such as this one here.
Seismic station PMM is in Parkfield, California.

UTC = Universal standard time (Greenwich, England)

PDT = Pacific daylight time

S - P = 9 min 30 sec = 570 seconds
Liquefaction

- Some rocks behave as liquids when shaken by earthquake waves (soft sands, clays, water-logged sediments, land-fill).
- Such materials are known as thixotropic.
- The process is called liquefaction.
- Liquefaction magnifies the effects of earthquakes. It results in ground movement, slumping and landslides, causing buildings to collapse. It is a very serious contributor to earthquake damage.
Landslide at Turnagain Heights, Alaska, 1964

A very good example of liquefaction
Liquefaction – Sand Boils

Examples of sand boils
Tsunamis

“The great wave off the coast of Kanagawa” a famous picture by the Japanese artist Hokusai (1823-1829)
What on Earth is a Tsunami?

- Tsunami (Japanese) means harbor wave.
- Tidal Wave (English) is not strictly correct, since tides imply the influence of the moon.
- Tsunamis are mostly generated along, or close to, the deep ocean trenches of the Pacific Ocean. They are caused by:-
  - Faulting (earthquakes)
  - Landslides
  - Volcanic eruptions
It is mostly reverse faults that trigger tsunamis.
Notice how the wave height increases as it approaches the shore.
Wave heights are typically between 8 to 40 feet (100 ft waves have been recorded).
Wave heights can be amplified by the coastline.
The interval between waves can vary from minutes to hours.
The speed of the waves is proportional to the water depth, and therefore decreases as it approaches the shore.
Example of changes in water level associated with a small tsunami at Hilo, Hawaii in 1975.
Calculating the Tsunami Wave Speed

\[ \text{Tsunami Wave Speed} = \sqrt{GD} \]

- \( G \) = gravity (980 cm/sec\(^2\))
- \( D \) = depth in centimeters

Assume an earthquake occurs in a deep ocean trench at a depth of 6 km, then:

\[ \text{Tsunami Wave Speed} = \sqrt{980 \times 6 \times 100,000} \]

\[ = \sqrt{588,000,000} \]

\[ = 24,249 \text{ cm/sec} \]

or \( 24,249/100,000 \times 60 \times 60 \text{ km/hr} \)

\[ \text{Tsunami Wave Speed} = 871 \text{ km/hr} \quad (540 \text{ miles/hr}) \]
Scotch Cap lighthouse, Aleutian Islands was completely destroyed by a tsunami following an earthquake in the Aleutian islands in 1946. The lighthouse was 40 ft above the water, but the tsunami produced 100 ft waves!
The same 1946 Aleutian Island earthquake produced a tsunami that traveled 3,800 miles across the Pacific Ocean, devastating Hilo on the Big Island of Hawaii.

18–24 ft waves coming ashore in Hilo
Tsunami breaking over the pier in Hilo, Hawaii

$26 million in damage, 159 deaths
Hilo, Hawaii, 1946

Waterfront buildings were washed across the street crashing into other buildings.
Once again, in 1960, Hilo was devastated by a tsunami. This one originated in Chile, 10,000 miles away!
Japan, 1983

Initial phase – water withdraws

Flooding

Afterwards

$800 million damage
104 people drowned
Valdez, Alaska, 1964

Earthquake caused land to slide into the sea, carrying dock and part of town with it. Tsunami with 32 ft. waves followed. $150 million in damage and 30 deaths.
Sumatran Earthquake and Tsunami
December 26th, 2004

- Megathrust along subduction zone between Australian plate and Burma and Sunda microplates.
- 1200 km long displacement zone, most of which occurred 500 km N.W. of epicenter.
- Maximum of 20 m displacement
- Magnitude 9.0
- Fourth largest earthquake since 1900 A.D. and largest since 1964 Alaska earthquake.
- Equivalent to 475 megatons of TNT (23,000 Nagasaki A-bomb).
- Triggered a massive tsunami
Tsunami traveled across entire Indian Ocean, affecting Indonesia, Malaysia, Thailand, India, Sri Lanka, Maldives, Somalia, Madagascar and Tanzania. Maximum wave height was about 25 m (80 ft).

**Travel Times**

India ~ 2 hours

E. Africa ~ 7 hours
Wave coming ashore at holiday resort in Malasia

Vegetation stripped from low-lying areas by waves
The worst hit area was Banda Aceh in N. Sumatra, Indonesia.
The tsunami warning system was established in 1946 following a devastating tsunami in Hawaii. Pacific Ocean-wide network of:

- Seismic Station
- Tsunami Buoys
- Coastguards
- Civil defense
These buoys measure changes in water depth, thereby indicating the passing of tsunami waves.

Following the 1996 Sumatran earthquake and tsunami, there are plans to increase the number of tsunami warning buoys in the Pacific and Indian oceans.
Japanese Earthquake and Tsunami
March 11, 2011  Magnitude = 9.0

CONSEQUENCES
Affected 804 km of east coast
Inundated 130 sq. km of land
Dead ~ 15,854
Missing ~ 3,272
Homeless ~ 131,000
Economic Loss ~$309 billion

PBS Nova Video
Miyako
Kessennuma
Ostuchi