Waves

Parts of a wave:

- height (H)
- wavelength (L, or λ)
- amplitude (H/2)
- crest
- trough
Wave as an oscillation
Waves are energy

The energy moves through the water as a wave form.

The water particles move in circles (orbits) as the wave passes.

REALLY important point related to tsunamis:

The longer the wavelength, the faster the wave.

\[ C = 1.25 \times \sqrt{\text{wavelength}} \]
Wave speeds

*Deep-water wind waves*

**Maximum values:**

- **Period**: 20 seconds
- **Wavelength**: 600 meters
- **Speed**: 110 kilometers per hour
  
  *(70 mph)*

*Seismic sea waves* (*shallow-water waves*)

**Maximum values:**

- **Period**: 20 minutes *(60x wind waves)*
- **Wavelength**: 200 kilometers *(120 miles)*
- **Speed**: 760 kilometers per hour
  
  *(470 mph)*
Wave speed: Celerity

\[ C = \frac{L}{T} \] (equivalent to \( R = \frac{D}{T} \))

For surface waves in water, the longer the wavelength, the faster the celerity.

Wave dispersion, away from a storm center.
Wave dispersion away from a storm

Long wavelength waves move out ahead

(a) DEEP-WATER WAVE TRANSFORMATIONS
Waves in shallow water

Energy is lost from the wave because of friction with the bottom

As a wave moves into shallow water:
- speed decreases
- wavelength decreases
- height increases
Waves in shallow water

Intermediate wave  Shallow-water wave  Surf zone  Swash zone

Wavelength  \( L_1 \)  \( L_2 \)  \( L_3 \)  \( L_4 \)

Height  \( H_1 \)  \( H_2 \)  \( H_3 \)  \( H_4 \)  \( H_5 \)

1 m water depth

\( L_1 > L_2 > L_3 > L_4 \)
\( H_1 < H_2 < H_3 < H_4 < H_5 \)

vertical exaggeration = 20 x

wave speed decreases
wave length decreases
wave height increases

(b) SHALLOW-WATER WAVES IN PROFILE
Depth < 1/2 wavelength

Surf zone
Surging wave
Scale of a tsunami

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Tsunami

*Tsunami* is Japanese for “harbor wave”

Caused by the vertical displacement of ocean water

Triggered by:
- Large earthquakes that move the sea floor
- Underwater landslides
- Volcano flank collapse
- Submarine volcanic explosion
- Asteroids

Another category: *Mega tsunami*
Ways to create a tsunami

Subduction-zone earthquake larger than $M \geq 7-7.5$

100 years later stored tension

Fault rupture
Response after earthquake

0 minutes

10 minutes

20 minutes
Figure 3.6

1. Rupture on seafloor produces seismic wave

2. Wave moves rapidly across ocean (400 mph)

3. Wave slows (25 mph) and steepens near shore

4. Uprush of wave inundates and destroys coastal zone
Tsunami path through the ocean
Meulaboh, Indonesia
Meulaboh, Indonesia
Banda Aceh, Indonesia
Banda Aceh, Indonesia
Kata Noi receding wave
Water receding from shoreline
Water receding from shoreline
Ways to create a tsunami

Submarine
landslide
on edge of
slope
Submarine landslide
Simulation of landslide-induced wave
Minimizing the Tsunami Hazard

Detection and warning
Monitor earthquake zones

Tsunami warning system
Seismographs to detect earthquakes
Tidal gauges to determine sea level changes
Buoy sensors to detect tsunami in open ocean

Structural control
Building codes for susceptible coastline areas

Run-up maps
Show the height to which water is likely to rise
**Tsunami warning system**

**Communications buoy**
Receives data from ocean floor along with readings from surface weather instruments, and relays to a satellite.

**Bottom-pressure recorder**
Can detect minute changes in water pressure caused by a passing tsunami as small as 0.4 in (1 cm)

- Flotation device
- Batteries
- Computer
- Anchor chain: Up to 19,700 ft. (6000 m) long
- Anchors: 6850 lbs. (3107 kg)
Tsunami run-up map

PACIFIC OCEAN

Kaena Point 36

Waialua
Wahiawa
Waimanalo
Pearl City
Ewa Beach
Pearl Harbor
Honolulu
Makapuu Point

PACIFIC OCEAN

Maximum runups (in ft.)

22

19

27

14

Kahana

Kahana Bay

Kahuna Point

Kahua

Kawal Point

Kawal Bay

Kaeiiwa

Mokapu Point

0 100 Miles

0 100 Kilometers
TSUNAMI HAZARD ZONE

IN CASE OF EARTHQUAKE, GO TO HIGH GROUND OR INLAND
Mega tsunami
Mega tsunami
North Atlantic Ocean

Azores

Canary Is.

Cape Verde Is.
Tenerife,
Canary Islands
Orotova landslide

Mt. Teide
Alika submarine landslide
A lika submarine landslide

At least 60 m of run-up
Drop
Asteroid impact
Volcanoes
Volcanoes occur in what tectonic settings?

Subduction zones (convergent margins)
Volcanic island arcs
Coastal mountain ranges  
\textit{Difference?}

Hot spots
Oceanic crust
Continental crust  \textit{Examples?}

Continental rifting zones  \textit{Example?}

Mid-ocean ridge  
\textit{Is this a problem to people anywhere?}
Tectonic settings for volcanoes

Subduction zones
Mid-ocean ridge
Hot spots
Continental rifting
Where, geographically, are most of the volcanoes?
Volcanic island arc

An example is...
Volcanic island arc – Japan
Where?

What feature?

Name of a famous volcano?
Mt Kilimanjaro
Mantle plumes and continental rifting
Which ocean? Many active volcanoes?
Where?

What is happening?
Many volcanoes?
Subduction zone processes

- Sediment transported to deep ocean floor
- Sediment transported into basin
- Sedimentary rock
- Partial melting of metamorphic rock
- Sedimentary rock metamorphosed in subduction zone
- Hot mantle rock partially melts to form magma
What tectonic event?

Active volcanoes?

Other recent event?
Plate boundaries, volcanoes, & earthquakes
Types of volcanoes

Shield
- basalt flows

Cinder
- coarse ash

Composite
- layered
- Andesite or rhyolite
Which volcanoes flow?

Basaltic lava flows easily

Where could this be?
Which volcanoes explode?
Rhyolitic and andesitic lavas tend to explode water & gasses under pressure, viscous magma
Granite – Diorite – Gabbro

The EXTRUSIVE equivalent igneous rocks?

Rhyolite – Andesite – Basalt
<table>
<thead>
<tr>
<th>Composition and Texture</th>
<th>Coarse grained</th>
<th>Fine grained</th>
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</thead>
<tbody>
<tr>
<td>Magma type</td>
<td></td>
<td></td>
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<tr>
<td>Mafic</td>
<td>Gabbro</td>
<td>Basalt</td>
</tr>
<tr>
<td>(from mantle)</td>
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<tr>
<td>Intermediate</td>
<td>Diorite</td>
<td>Andesite</td>
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<tr>
<td>Felsic</td>
<td>Granite</td>
<td>Rhyolite</td>
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<tr>
<td>(continents)</td>
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</tbody>
</table>
Tectonics & types of igneous rocks

- Mid-ocean ridge
- Oceanic crust (deep)
- Convergent boundary
- Batholith
- Continental interior
- Volcanic ash coastal mt. range
Which volcano is more likely to erupt explosively?

Think about the tectonic setting of each, and the type of magma.

Mauna Loa, Hawaii

Mt. Fuji, Japan
View of the Big Island of Hawaii

Hawaiian "moat", elevation ~5,000 m below sea level

Kohala

Hualalai

Mauna Kea

Mauna Loa, summit elevation ~4170 m above sea level

Kilauea

Bathymetric and elevation data provided by University of Hawai'i School of Ocean and Earth Science and Technology, and US Geological Survey. Scale varies in this perspective view to the northeast.
Mauna Loa, Hawaii
Mt. Fuji, Japan
Geography: Where on North America are most of the active volcanoes?
Cascades
volcanoes of
the Pacific
Northwest

Subduction of
Juan de Fuca
plate
Volcanoes produced by subduction

Juan de Fuca plate is young, hot, low density
The Cascades, Washington and Oregon

Hood

Jefferson

St. Helens
Mount St. Helens before eruption 1980
Mt. St. Helens eruption sequence
Bulge on NE flank prior to eruption
Initial blast – 500x the Hiroshima bomb
Mount St. Helens
Mount St. Helens

After eruption (7 years later)
States (or Phases) of Matter

- **GAS**
  - gas disorder

- **LIQUID**
  - liquid short range order

- **SOLID**
  - solid long range order
Controls on phase transitions

Phase transitions are controlled by:
  heat (energy available – outward force)
  pressure (constraining force)
Phase transitions and rocks

Most rocks are made of more than one mineral. Each mineral melts at a different temperature.

So, a rock can be *partially molten* – with liquid in between solid crystals.
Phase transitions and rocks

Can a rock in the upper mantle melt without an increase in temperature?

Earth surface

- Uplifted, pressure reduced
- Partial melting
- Produces magma

Rock initially at a temperature close to melting
What happened here?
Forming a caldera – Crater Lake, Oregon
Forming a caldera