Module 3

Geology Related Disasters

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Module 3: Geology Related Disasters

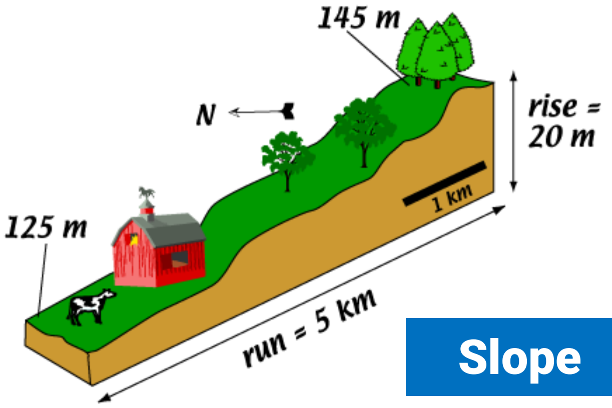
Landslides and Mudflows, Earthquakes, Dam Failures / Dam Bursts, Mine Fires, Tsunami – Definition, Cause, Types, Safety Precautions

What is a Landslide?

Landslide is a general term that describes the **downslope movement of soil, rock, and organic materials** under the effects of gravity and the landform that results from such movement.

Other phrases/terms used for landslides

- Mass movement
- Slope failure etc



Slope

Source: https://www.humanitarianlibrary.org/sites/default/files/2020/06/The-Landslide-Handbook_USGS.pdf
https://www.indiaspend.com/development/india-needs-an-urgent-early-warning-system-for-landslides-but-challenges-abound-838036

What causes landslides?

There are two primary categories of causes of landslides: **natural and human-caused**. Sometimes, landslides are caused, or made worse, by a combination of the two factors.

Natural Occurrences

This category has three major triggering mechanisms that can occur either singly or in combination

(1) water

(2) seismic activity

(3) volcanic activity

Effects of all of these causes vary widely and depend on factors such as the steepness of the slope, morphology or shape of the terrain, soil type, underlying geology, and whether people or structures are in the affected areas.

Landslides due to water

Landslides and flooding are closely associated because both are related to precipitation, runoff, and ground saturation by water.

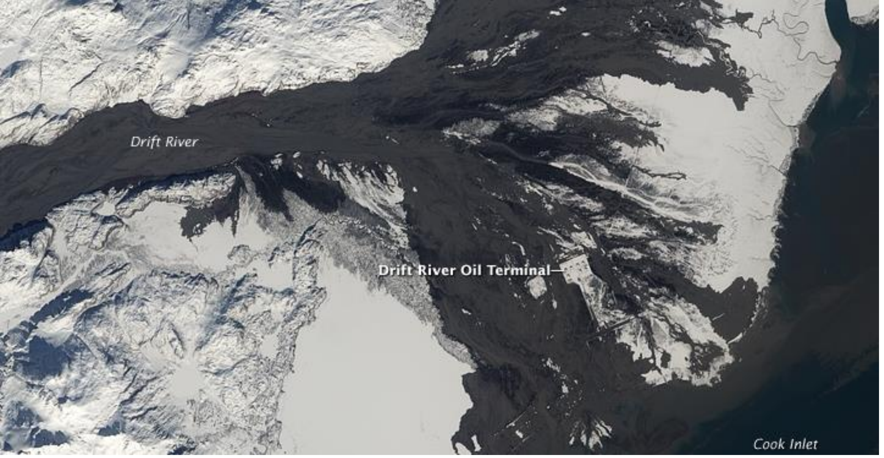
Slope saturation by water

Saturation can occur in the form of intense rainfall, snowmelt, changes in ground-water levels, and surface water level changes along coastlines, earth dams, and in the banks of lakes, reservoirs, canals, and rivers. Landslides and flooding are closely associated because both are related to precipitation.

Landslides due to seismic activity

Earthquakes in steep Landslide-prone areas significantly increase the likelihood of landslides due to ground shaking alone, liquefaction of susceptible sediments, or shaking-caused dilation of soil materials, allowing rapid infiltration of water.

Rockfalls and rock topples can also be caused by loosening rocks or rocky formations due to earthquake ground shaking.



Landslides due to volcanic activity

Landslides due to volcanic activity represent some of the most devastating types of failures. Volcanic lava may melt snow rapidly, which can form a deluge of rock, soil, ash, and water that accelerates rapidly on the steep slopes of volcanoes, devastating anything in its path.

These volcanic debris flows (also known as lahars, an Indonesian term) can reach great distances after they leave the flanks of the volcano and can damage structures in flat areas surrounding the volcanoes.

Volcanic edifices are young, unconsolidated, and geologically weak structures that, in many cases, can collapse and cause rockslides, landslides, and debris avalanches.

Human causes of landslides

- Populations expanding onto new land and creating neighborhoods, towns, and cities is the primary means by which humans contribute to the occurrence of landslides.
- Disturbing or changing drainage patterns, destabilizing slopes, and removing vegetation are common human-induced factors that may initiate landslides.
- Other examples include the steepening of slopes by undercutting the bottom and loading the top of a slope to exceed the bearing strength of the soil or other component material.
- However, landslides may also occur in once-stable areas due to other human activities such as irrigation, lawn watering, draining of reservoirs (or creating them), leaking pipes, and improper excavating or grading on slopes.
- New construction on landslide-prone land can be improved through proper engineering (for example, grading and excavating) by first identifying the site's susceptibility to slope failures and by creating appropriate landslide zoning.

Basic landslide types

Classification of landslides on the basis of type of movement and the type of material involved

1. Rock
2. Soil (Earth, if composed of sand-sized or finer particles
3. Debris (coarser fragments)

Type of movement

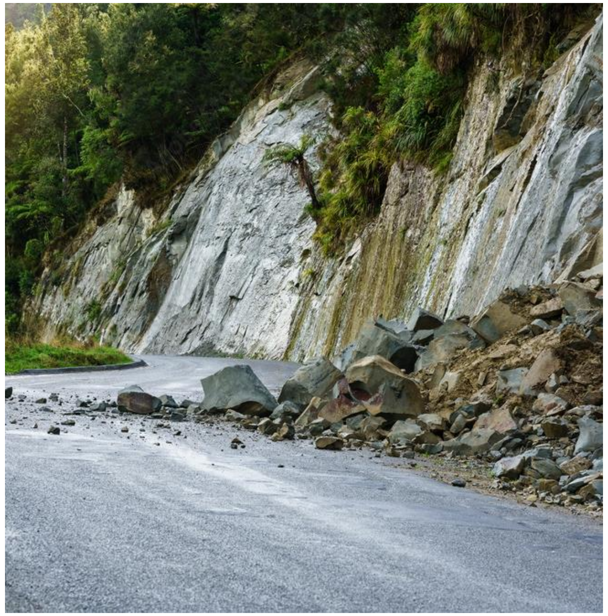
1. Fall
2. Topple
3. Slide
4. Spread
5. Flow

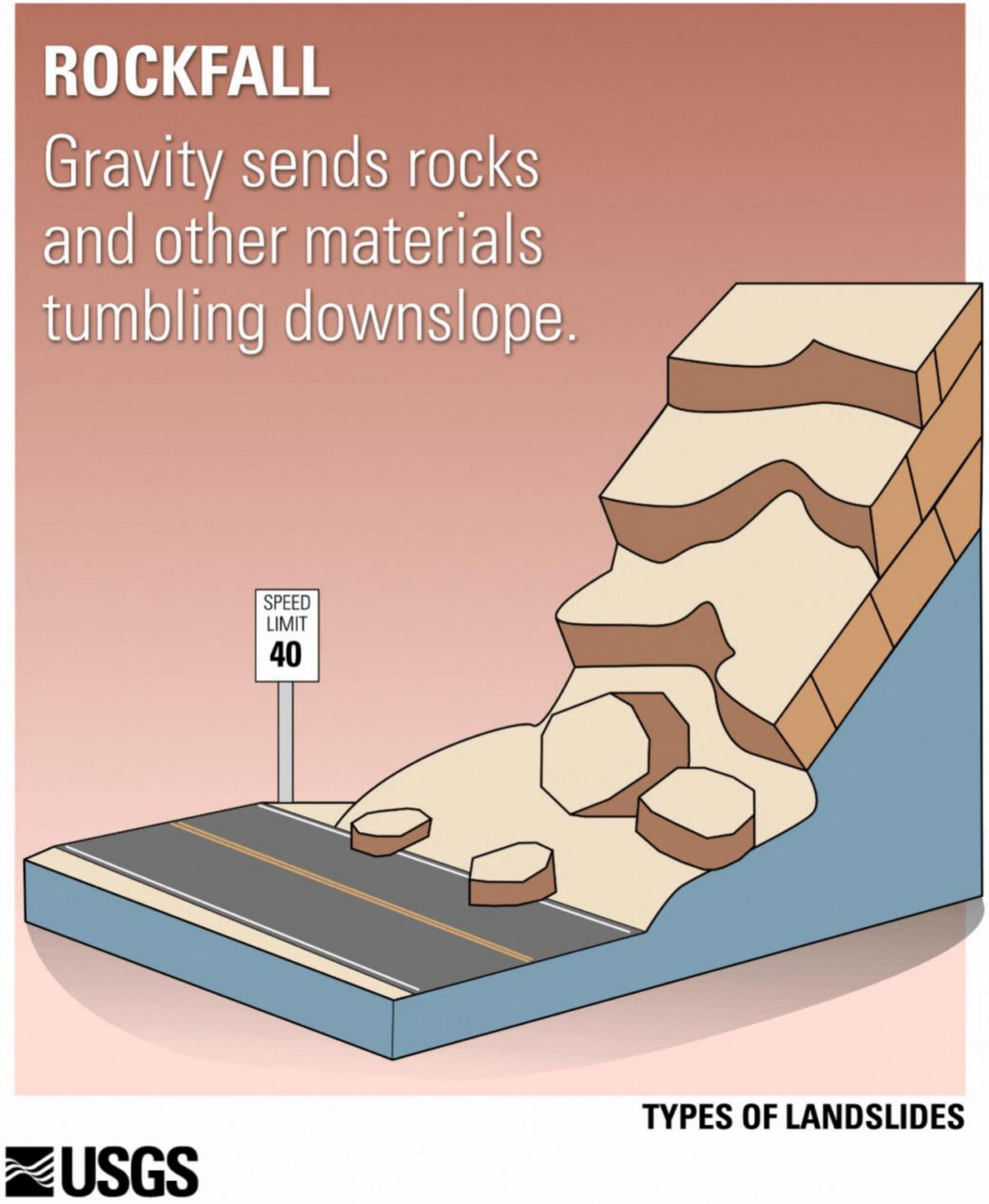
specific properties and characteristics

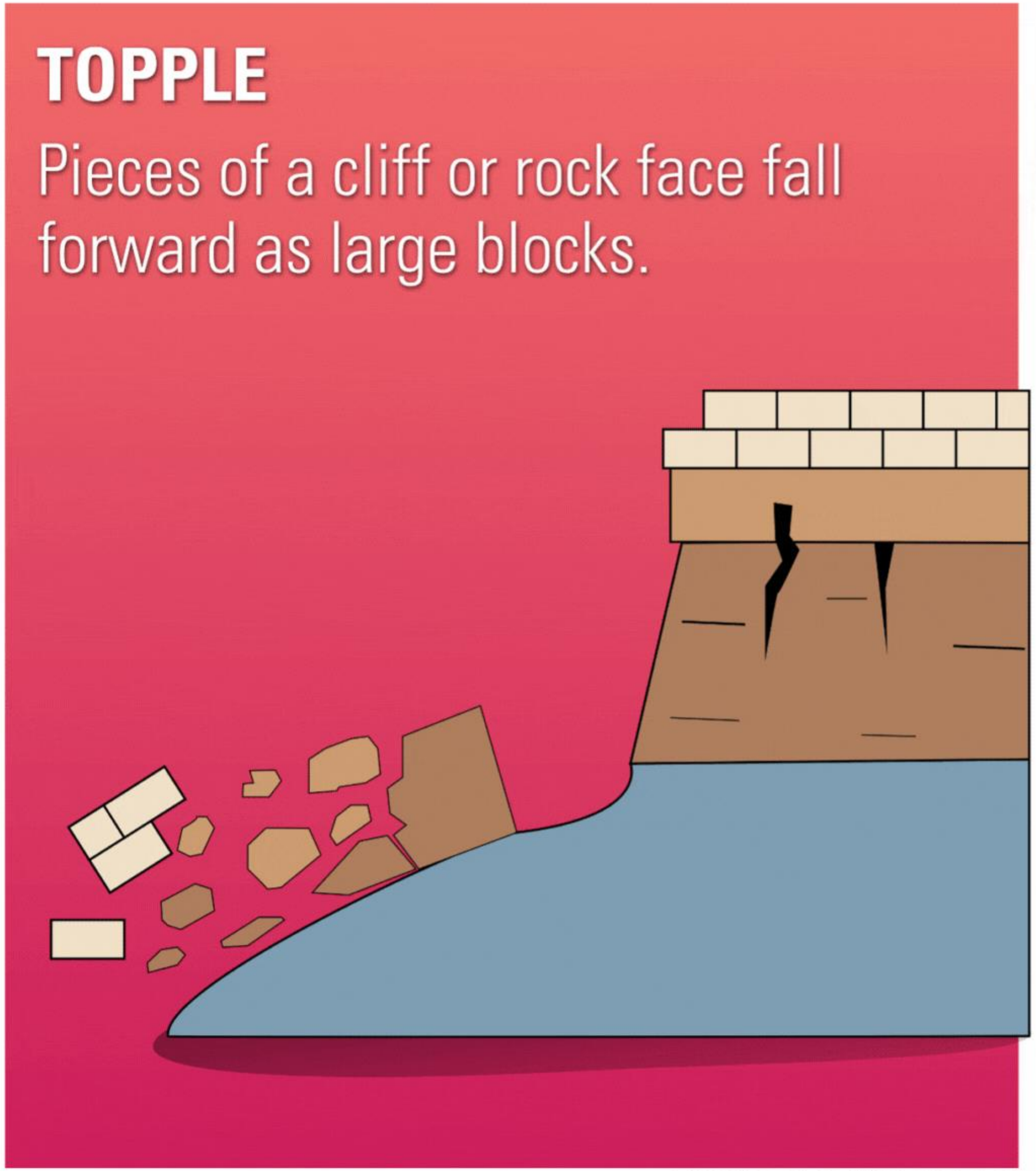
Are there chances of only more than one movement? Yes, rockslide—debris flow

Basic landslide types

Type	Description	Subtypes
Falls	It is a fall mass movement produced by the **detachment of rocky material or soil**. It falls or descends by rolls down steep slopes.	Rockfall
Topple	A topple can be produced by **gravity or the pressure of water/ice in the cracks of a big mass of rock material or soil**. Its movement can occur with coarse materials and fine-grained materials.	Complex topple Composite topple
Slides	A landslide is produced by a break in the surface or shear zones, causing a **displacement of rock masses or soil that grows from the local fault area**.	Rotational landslide Transitional landslide
Spread	A mass ma **cohesive material generated by the liquefaction** movement of (or flow) of nearby softer material.	Block spreads Liquefaction spreads Lateral spreads
Flows	It is the mass of earth, soil, and fine-grained material in the form of a flow. Sometimes it carries coarse material due to its water content.	Debris flow Lahars (Volcanic debris flow) Debris avalanche Earth flow Slow earthflow (Creep) Flows in permafrost

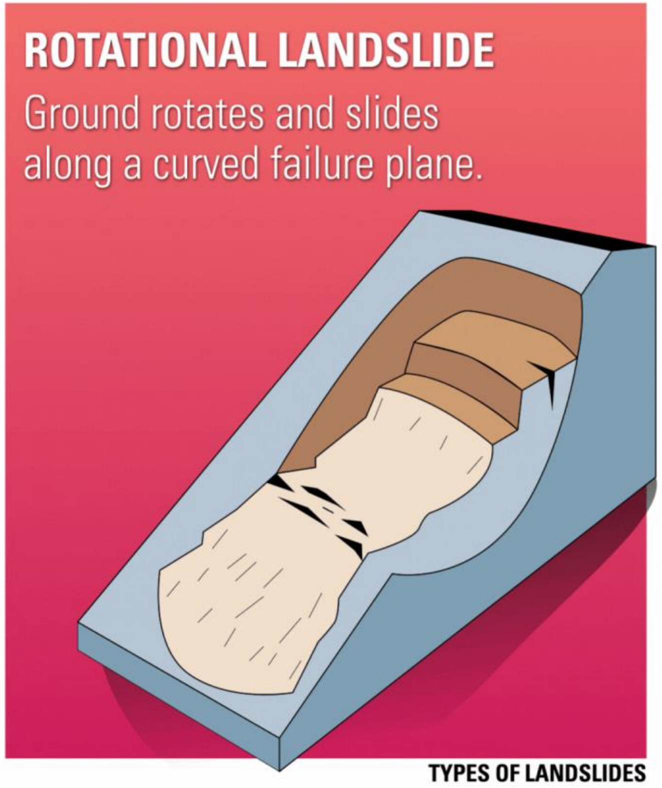


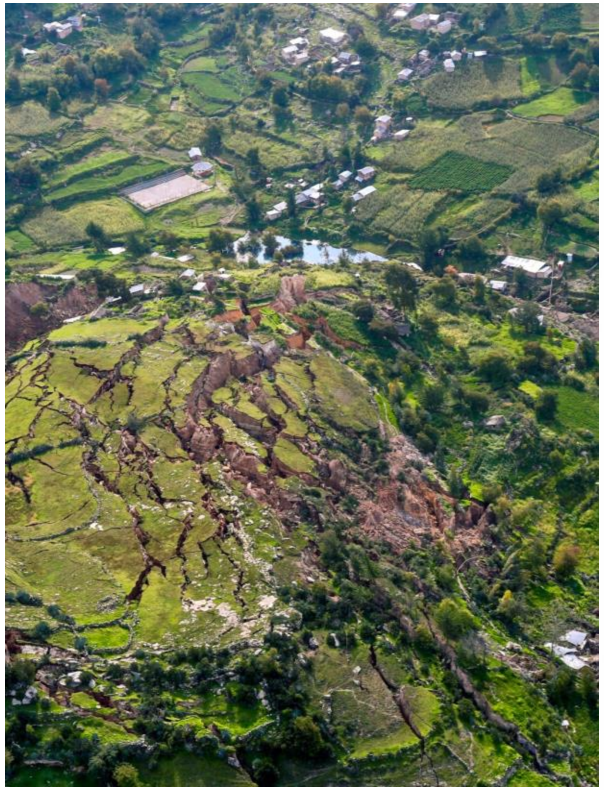

ROCKFALL
Gravity sends rocks and other materials tumbling downslope.
SPEED LIMIT 40
TYPES OF LANDSLIDES
USGS

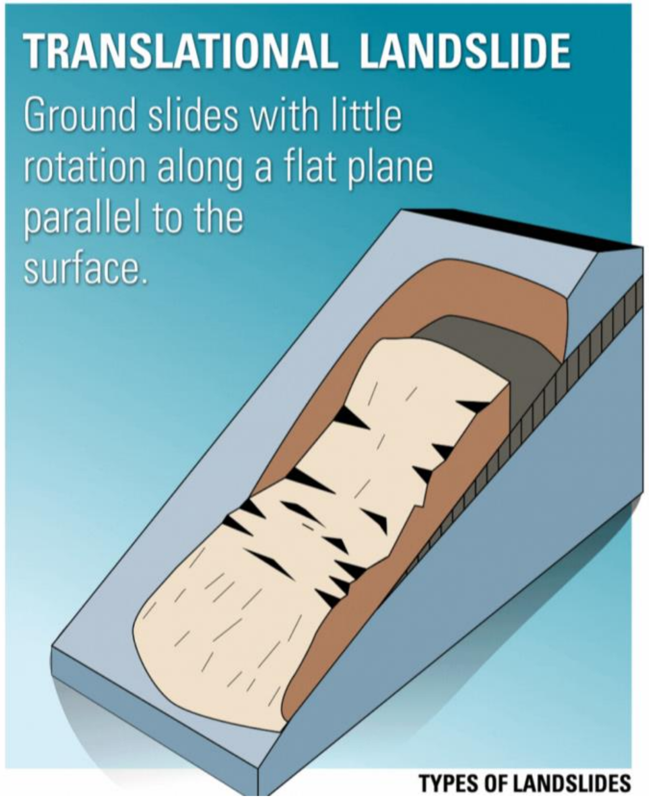


TYPES OF LANDSLIDES

Photograph of block toppling at Fort St. John, British Columbia, Canada.


ROTATIONAL LANDSLIDE
Ground rotates and slides along a curved failure plane.
TYPES OF LANDSLIDES

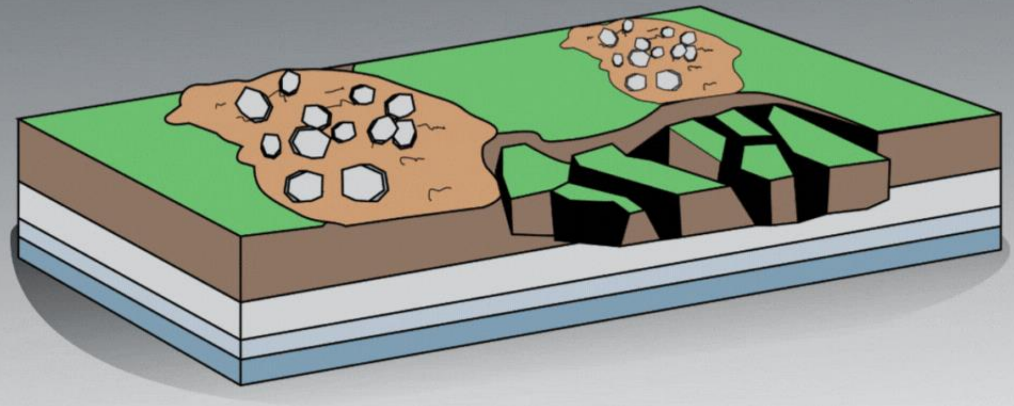



TRANSLATIONAL LANDSLIDE
Ground slides with little rotation along a flat plane parallel to the surface.
TYPES OF LANDSLIDES

Slides

LATERAL SPREAD

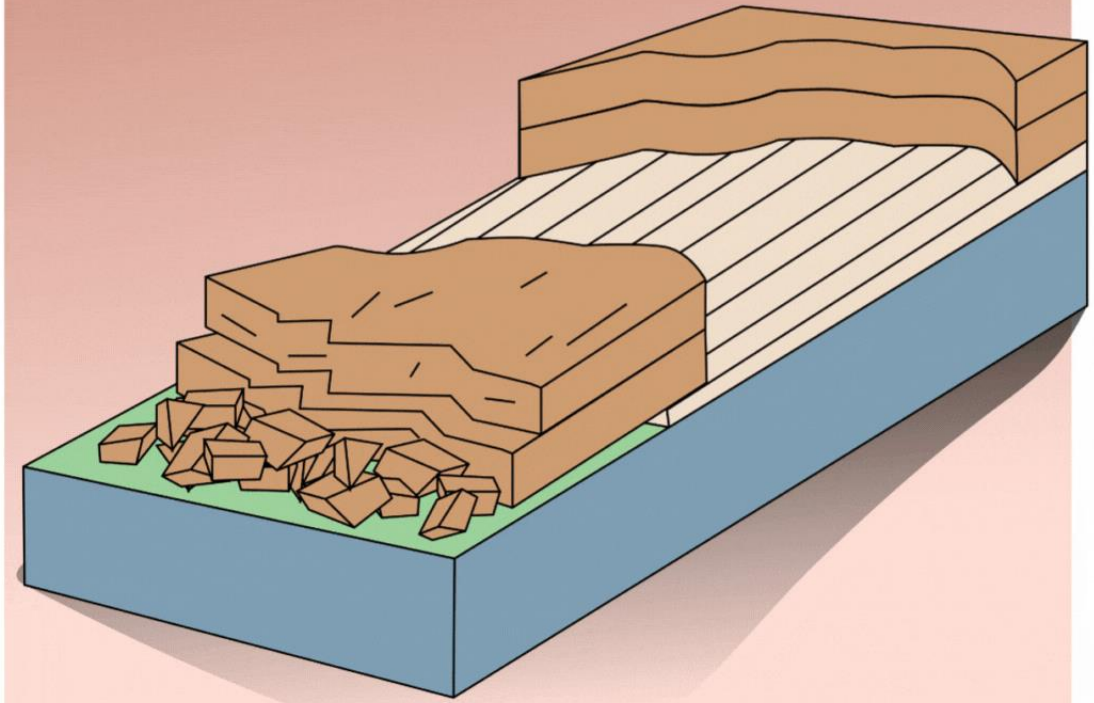
When surface material extends or spreads on gentle slopes. This type of ground deformation is often associated with earthquake shaking.



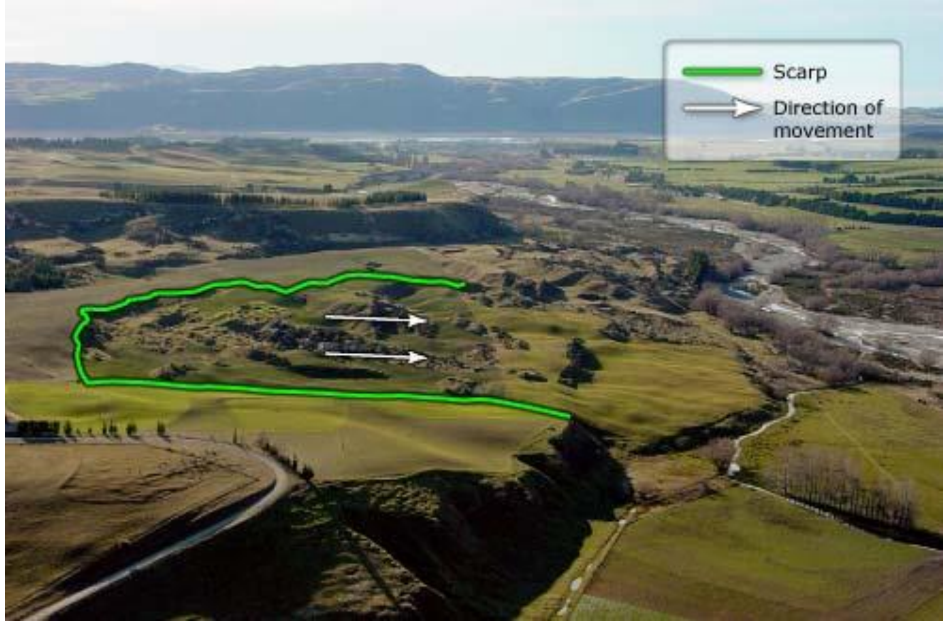
TYPES OF LANDSLIDES

BLOCK SLIDE

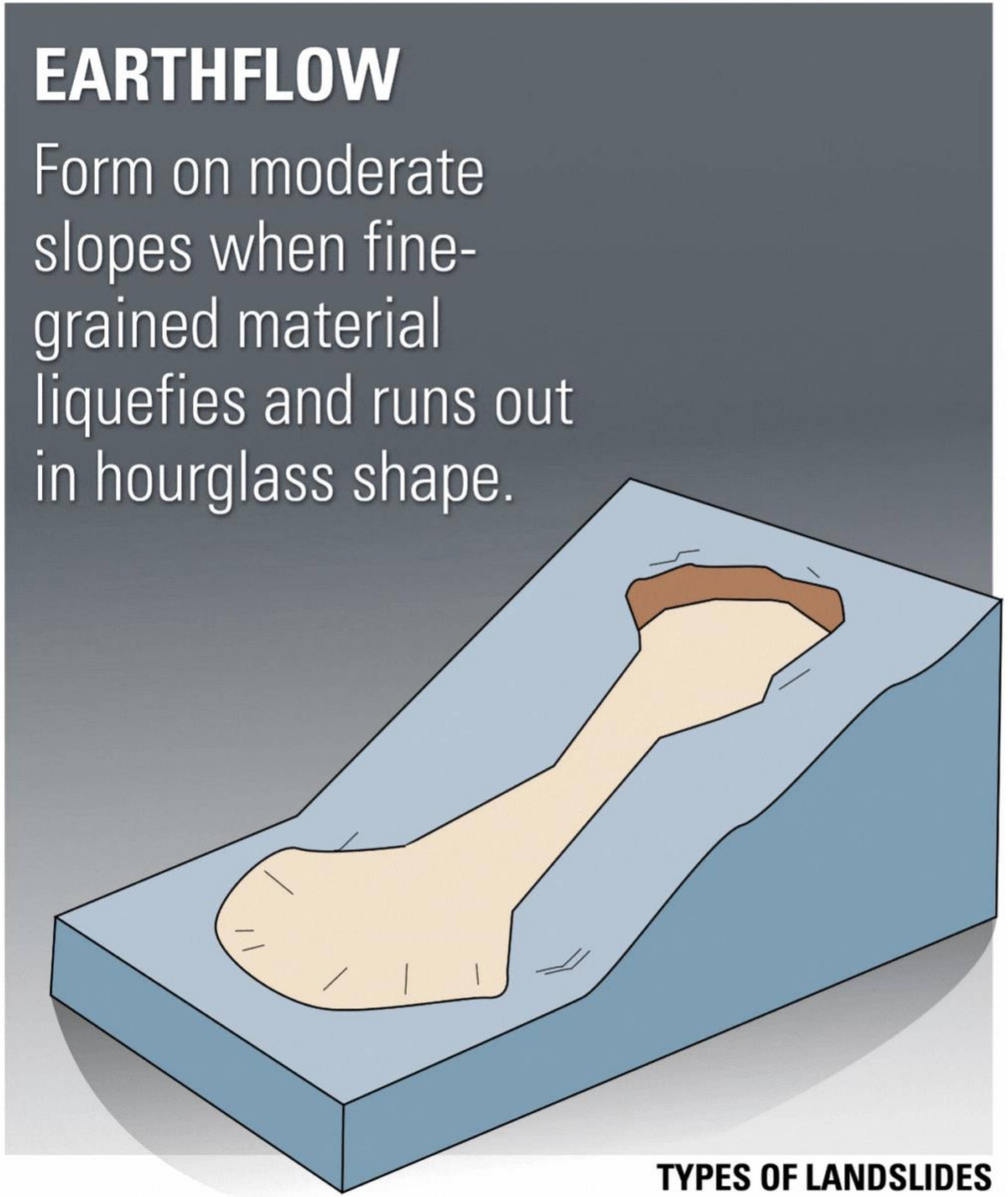
A type of translational landslide made of mostly one block of surface material that moves downslope.

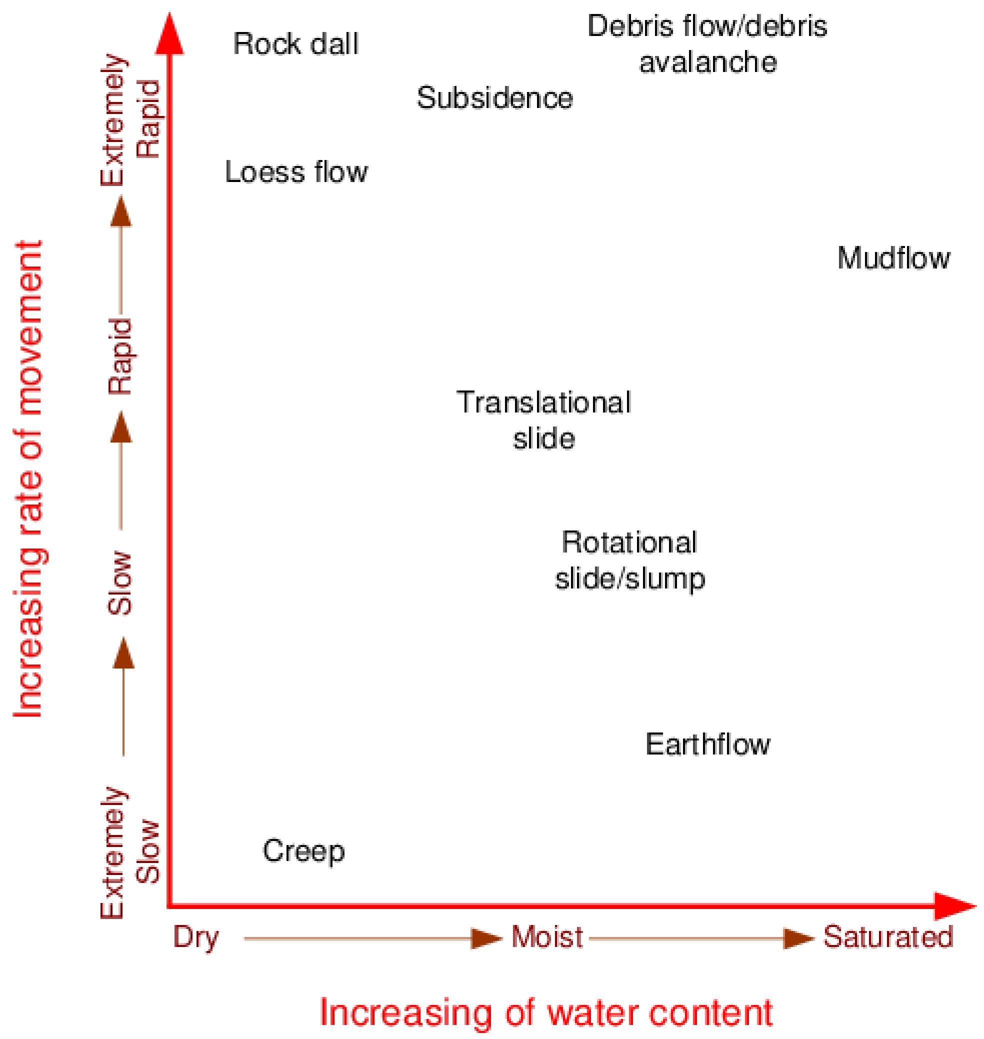


TYPES OF LANDSLIDES


Scarp
Direction of movement


CREEP
Soil and surface material that slowly moves down a slope.
TYPES OF LANDSLIDES

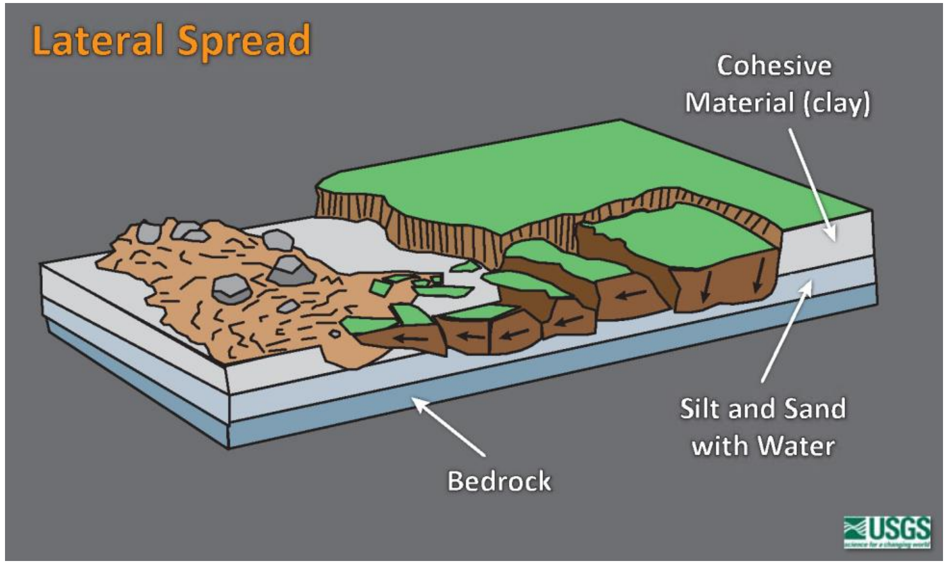

EARTHFLOW
Form on moderate slopes when fine-grained material liquefies and runs out in hourglass shape.
TYPES OF LANDSLIDES

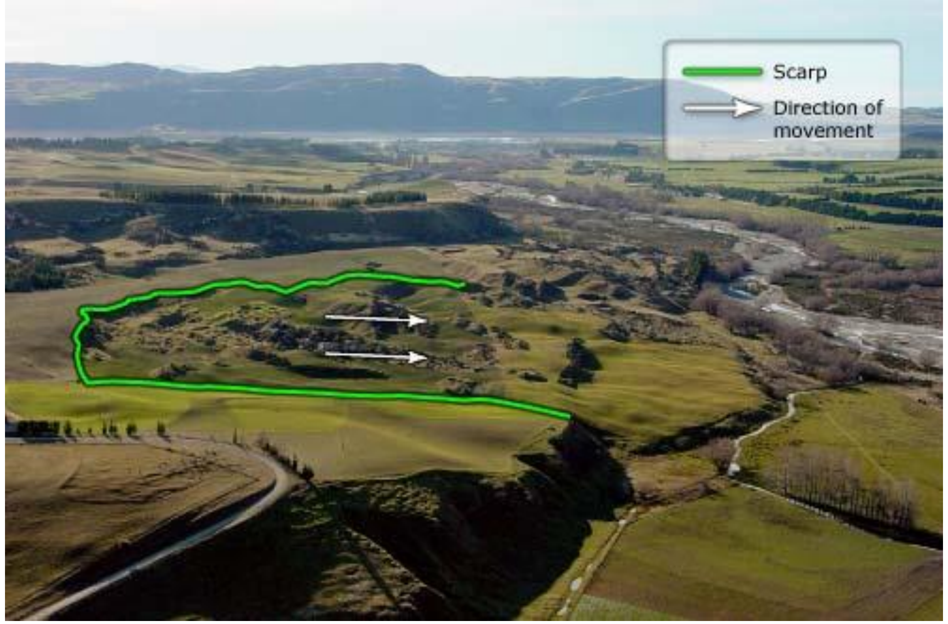


Relationship between increasing water content vs. Increasing rate of movement

Source: Widjaja et al. 2019

Spread


Lateral Spread
Cohesive Material (clay)
Silt and Sand with Water
Bedrock
USGS


Scarp
Direction of movement

Tsunami - nature and characteristics

- What is Tsunami?
- Characteristics of a Tsunami
- Impact of Tsunami
- What causes a Tsunami?
- Types of Tsunami generation
- Tsunami warning
- How are tsunamis measured or observed?

Tsunami

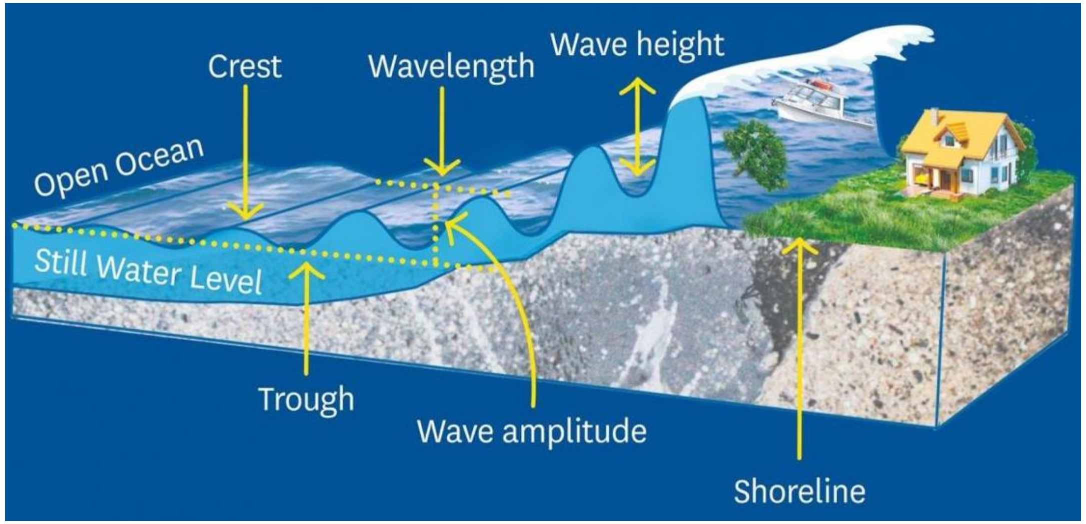
Tsu = harbor

Nami = wave

(Japanese terms)

A tsunami is a series of water waves of extremely long wavelengths and long periods generated in an ocean by a geophysical disturbance displacing the water within a short period.

Waves are formed as the displaced water mass, which acts under the influence of gravity, attempts to regain its equilibrium.



Source:https://www.learnz.org.nz/tsunami223/discover/tsunami
https://www.sciencedirect.com/science/article/abs/pii/B9780123744739006135

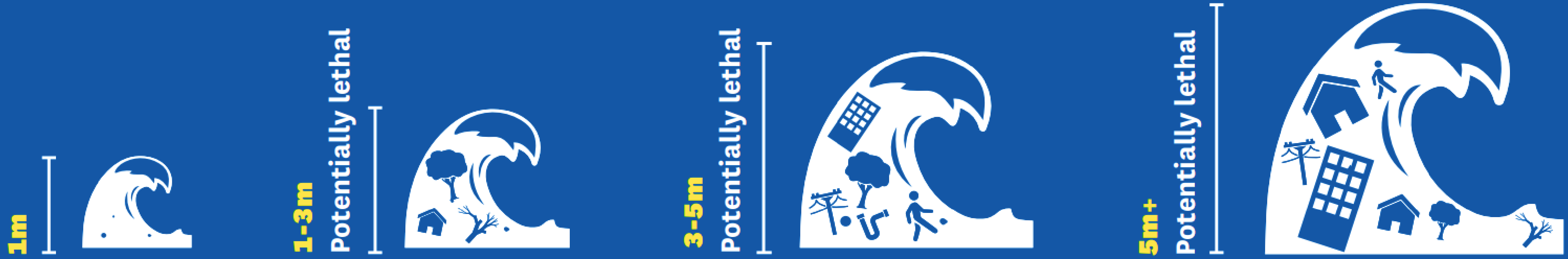
Characteristics of a Tsunami

- Tsunamis are different from normal waves
- Tsunamis have long wavelengths
- As a tsunami approaches land, the size increases
- Tsunamis are fast
- Tsunamis retain their energy
- Tsunami waves move outwards, away from their source
- A tsunami is a 'series' of waves
- Tsunamis can vary in size and severity





THE IMPACT OF TSUNAMI WAVES



Threat is mainly coastal. Some turbulence and strong currents.

Some damage to fragile coastal stuff like wooden buildings, machines and electrics.

Lots of damage and inundation. Damage to concrete buildings and coastal roads, pipes, electrical networks etc.

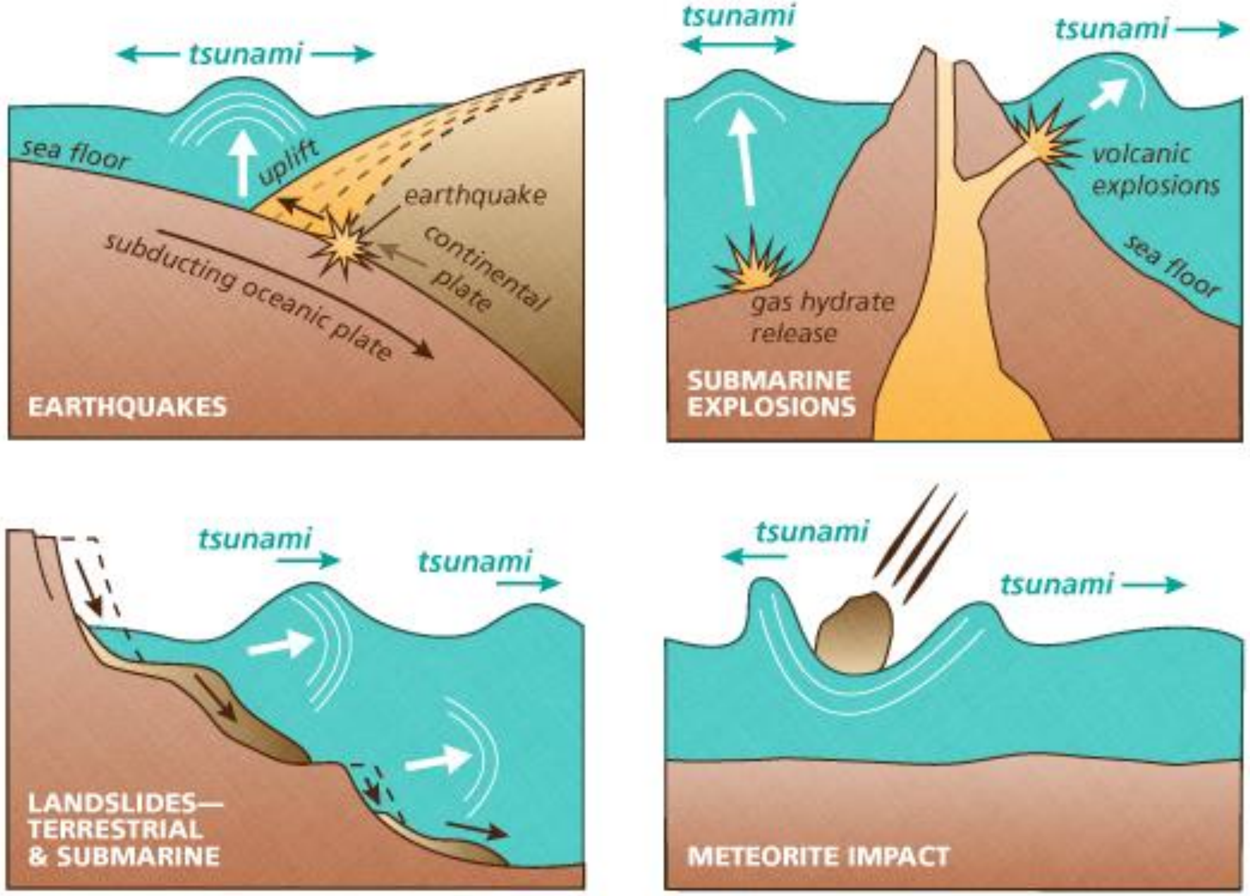
Lots of serious damage and inundation. Buildings, roads, bridges, pipes and wires washed away.

What causes a Tsunami?

Vertical movement of the seafloor related to

1. Subduction zone earthquakes
2. Submarine volcanic eruptions
3. Submarine landslides
4. Extraterrestrial: Meteor impact

Most tsunamis are caused by large earthquakes occurring below or near the ocean floor.



Subduction zone earthquakes

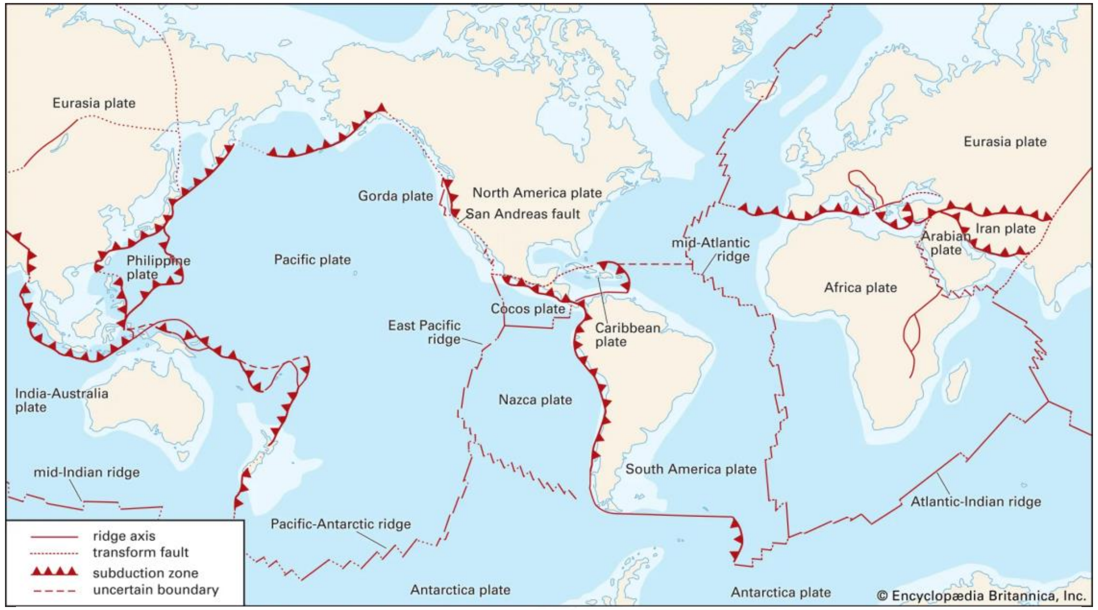
The plates are bounded by three types of features: ridge axes, where new seafloor is created in mid-ocean; transform faults, where plates slide past one another; and subduction zones, where plates overlap, with one plate sliding under the other.

The earthquake must occur beneath the ocean or cause material to slide into the ocean.

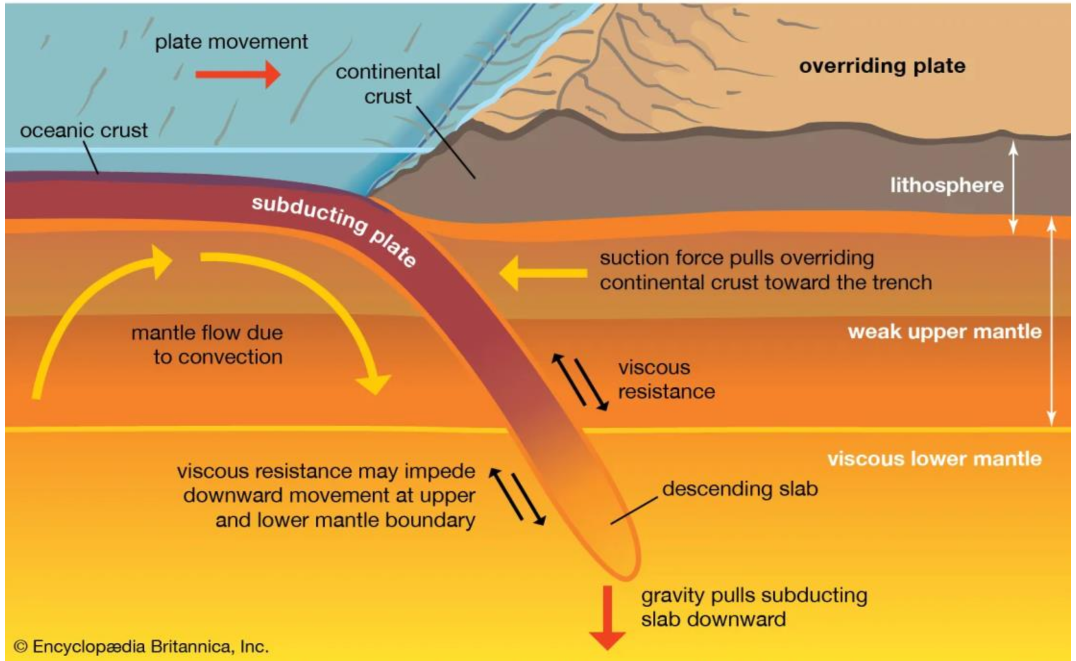
The earthquake must be strong, at least magnitude 6.5.

The earthquake must rupture the Earth's surface and occur at a shallow depth – less than 70km below the surface of the Earth.

The earthquake must cause vertical sea floor movement (up to several meters). This usually occurs with earthquakes along subduction zones.



Process of slab pull

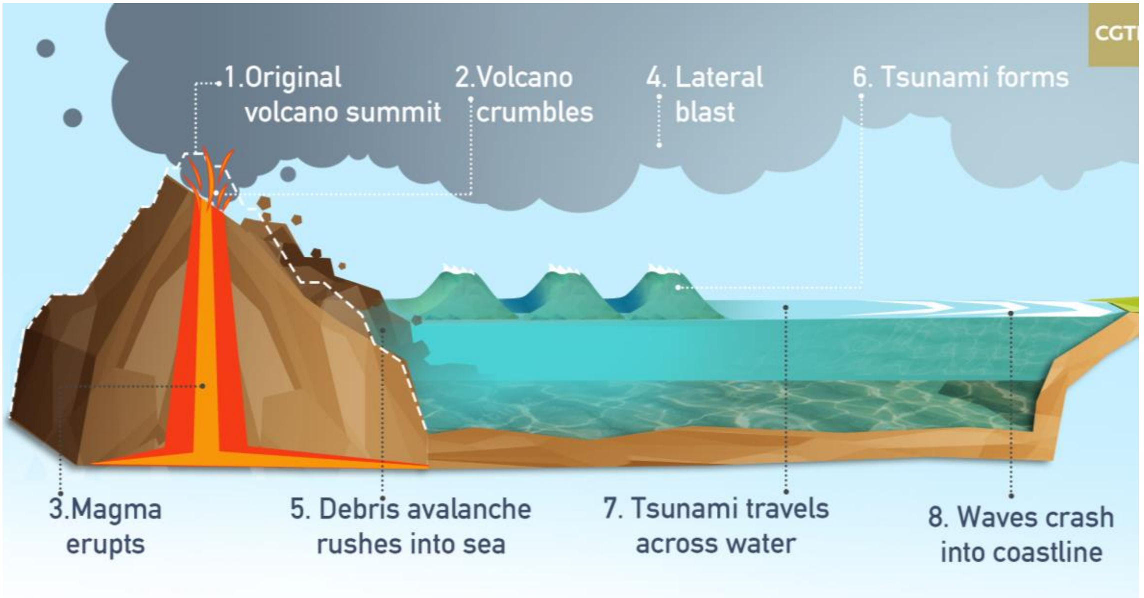


Source: https://uwiseismic.com/tsunamis/tsunamis-101/
https://www.britannica.com/science/subduction-zon

Submarine volcanic eruptions

Several types of volcanic activity can displace enough water to generate destructive tsunamis, including:

- Pyroclastic flows (flowing mixtures of rock fragments, gas, and ash)
- Submarine explosions relatively near the ocean surface
- Caldera formation (volcanic collapse)
- Landslides (e.g., flank collapse, debris flows)
- Lateral blasts (sideways eruptions)



Examples of volcano-generated tsunamis include:

August 27, 1883, Indonesia - The volcano Krakatau (Krakatoa) exploded and collapsed, generating one of the most giant and most destructive tsunamis ever recorded. Waves reaching 135 feet (41 meters) high destroyed coastal towns and villages along the coasts of Java and Sumatra and killed more than 34,000 people.

May 21, 1792, Kyushu Island, Japan - At the end of the four-month eruption of the Unzen volcano, a flank collapse generated a tsunami with waves reaching 180 feet (55 meters) high that caused destruction around the Ariake Sea and more than 14,000 deaths.

Source:https://www.noaa.gov/jetstream/tsunamis/tsunami-generation-volcanoes#:~:text=August%2027%2C%201883%20Indonesia%20%2D%20The,killed%20more%20than%2034%2C000%20people.

https://uwiseismic.com/tsunamis/tsunamis-101/

Submarine landslides

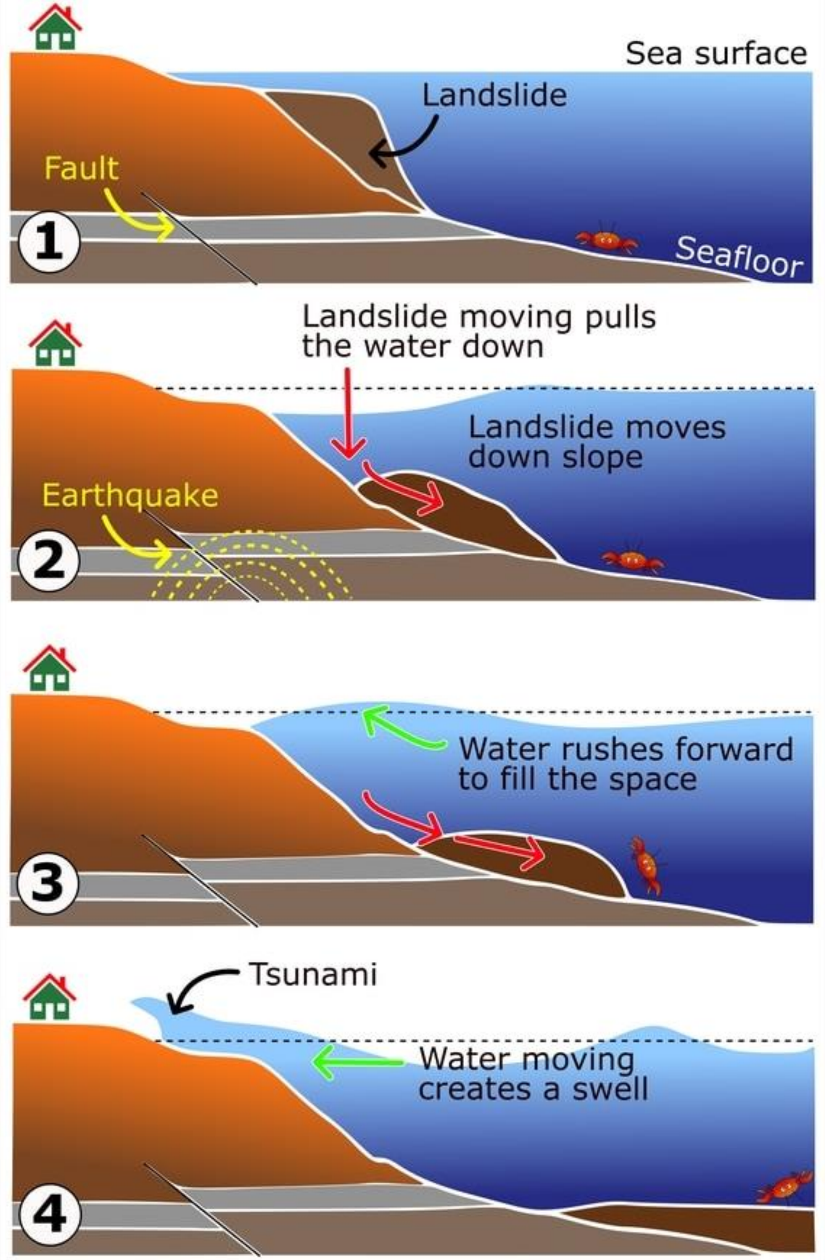
Both underwater and on-land landslides into the ocean can cause tsunamis.

In underwater landslides, the earth is moved to lower levels of the ocean basin due to gravity or a tectonic trigger, and this earth's movement pushes water in front of it which can cause a tsunami if enough earth is moved at once.

On-land landslides (huge chunks of glaciers, volcanoes, rockfalls, land, or other debris that slide into the sea) can cause tsunamis if the land along the coastline is forced into the ocean, creating a displacement of water.

Landslide-generated tsunamis are generally local tsunamis since the source is near the shore. The warning time may, therefore, only be a few minutes.

The largest tsunami reported in the Caribbean was possibly the landslide-generated tsunami that impacted Guadeloupe's northern coast. The event was triggered by an earthquake in 1867.



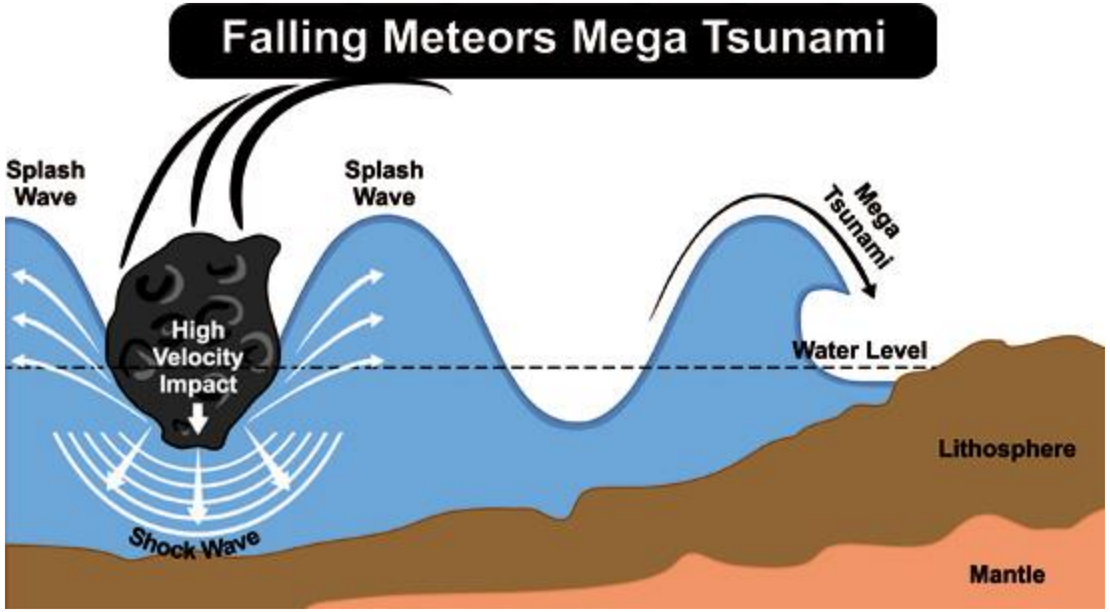
Source:https://www.noaa.gov/jetstream/tsunamis/tsunami-generation-volcanoes#:~:text=August%2027%2C%201883%20Indonesia%20%2D%20The,killed%20more%20than%2034%2C000%20people.
https://uwiseismic.com/tsunamis/tsunamis-101/

Extraterrestrial: Meteor impact

Extraterrestrial impacts from objects can also trigger tsunamis as falling debris from above displaces the water. These include:

- Asteroids
- Meteorites
- Comets

This is a rare event. Evidence suggests that an impact on the order of a 10-megaton explosion could occur once every few hundred thousand years.



Types of Tsunami generation

Near-field/ local Tsunamis

<1000 km

Waves have a very short travel time (30 minutes or less)

Far-field Tsunamis (Tele tsunami)

>1000 km

Waves travel time on an order of 30 to 3 hours

TYPES OF TSUNAMI WARNING

NATURAL

A long or strong earthquake

Sea level change

Unusual noises from the sea

Case study

NATURE | NEWS

Huge landslide triggered rare Greenland mega-tsunami

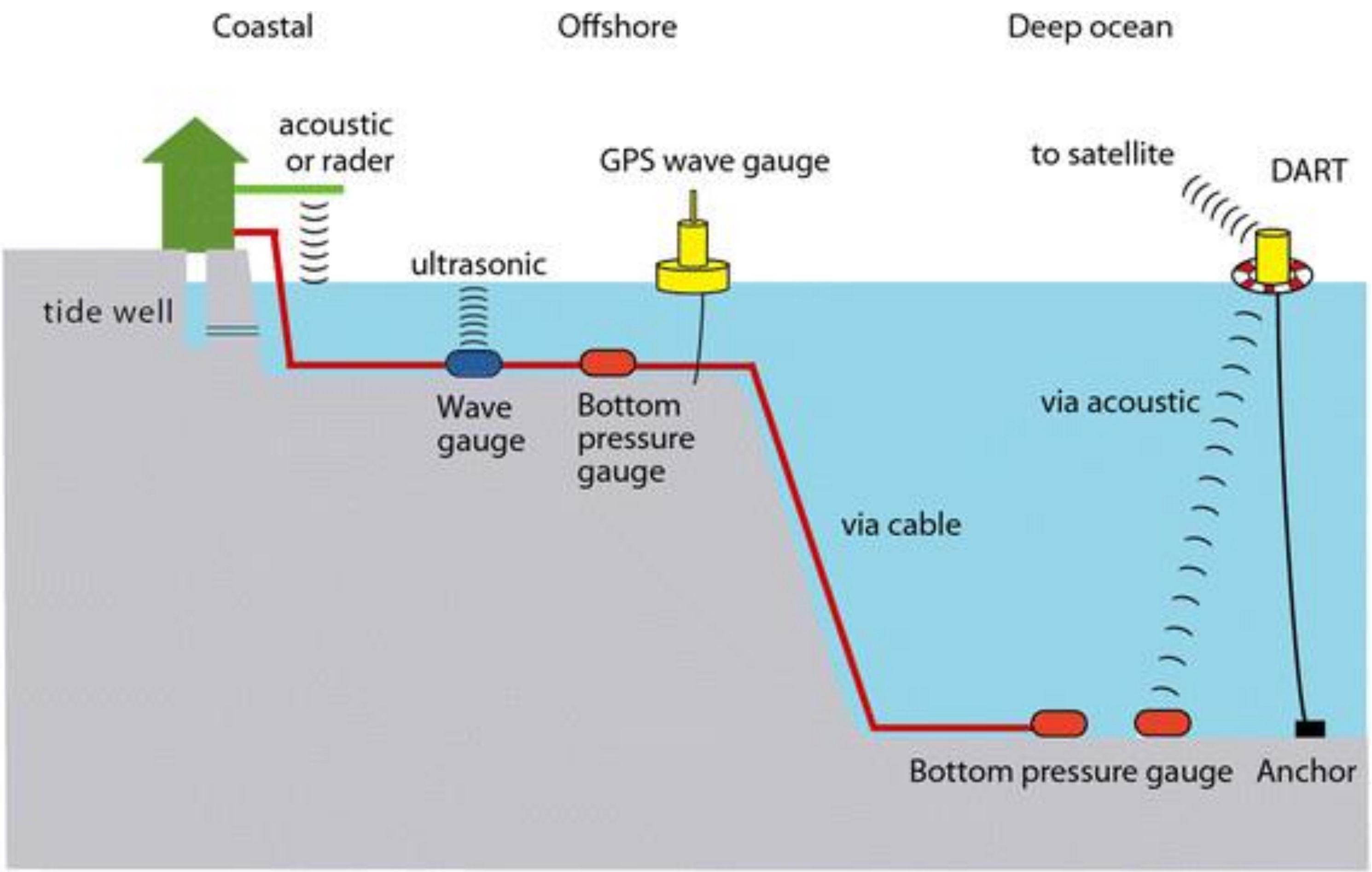
Scientists hope studying last month's deadly event will improve modelling of rockslides that could become more frequent with climate change.

Quirin Schiermeier

- **The landslide occurred on the evening of 17 June in the barren Karrat Fjord on the west coast of Greenland.**
- **It caused a sudden surge of seawater that wreaked havoc on the fishing village of Nuugaatsiaq, located on an island within the fjord about 20 kilometres away**
- **A 100-metre-high wave**

The GPS buoy is used as a wave gauge to detect tsunamis before their arrival on the coast.

EWS for Tsunami



Ultrasonic wave gauge to detect the wave height.

Deep-ocean Assessment and Reporting of Tsunamis (DART®)

Anchored seafloor bottom pressure recorder (BPR) and a companion moored surface buoy for real-time communications.

An acoustic link transmits data from the BPR on the seafloor to the surface buoy.

How are tsunamis measured or observed?

Bathymetry—the measurement of water depth of a body of water (e.g., ocean, sea, river, bay, lake, etc.)

Flow depth, tsunami flow depth, and direction—similar to tsunami height, tsunami wave height, or tsunami water level. Flow depth relates to the depth of the water from a tsunami, measured on shore in different locations; flow direction relates to the direction of this flow. See also Tsunami wave height below.

Inundation, or inundation distance—The horizontal distance inland that a tsunami penetrates, generally measured perpendicularly to the shoreline.*

Inundation line—Inland limit of wetting, measured horizontally from the mean sea level (MSL) line. The line between living and dead vegetation is sometimes used as a reference. In tsunami science, the landward limit of tsunami runup.*

Morphological change—The change in form or shape of an area (e.g., the beach) involving the motion of sediment, e.g., as caused by a tsunami wave.

Earthquake

- Earthquake basics
- Earthquake
- Seismology
- Seismic waves
- Measuring Earthquakes
- Locating earthquake
- Measuring the “size” of earthquakes
- Modified Mercalli Intensity (MMI)
- Richter scale

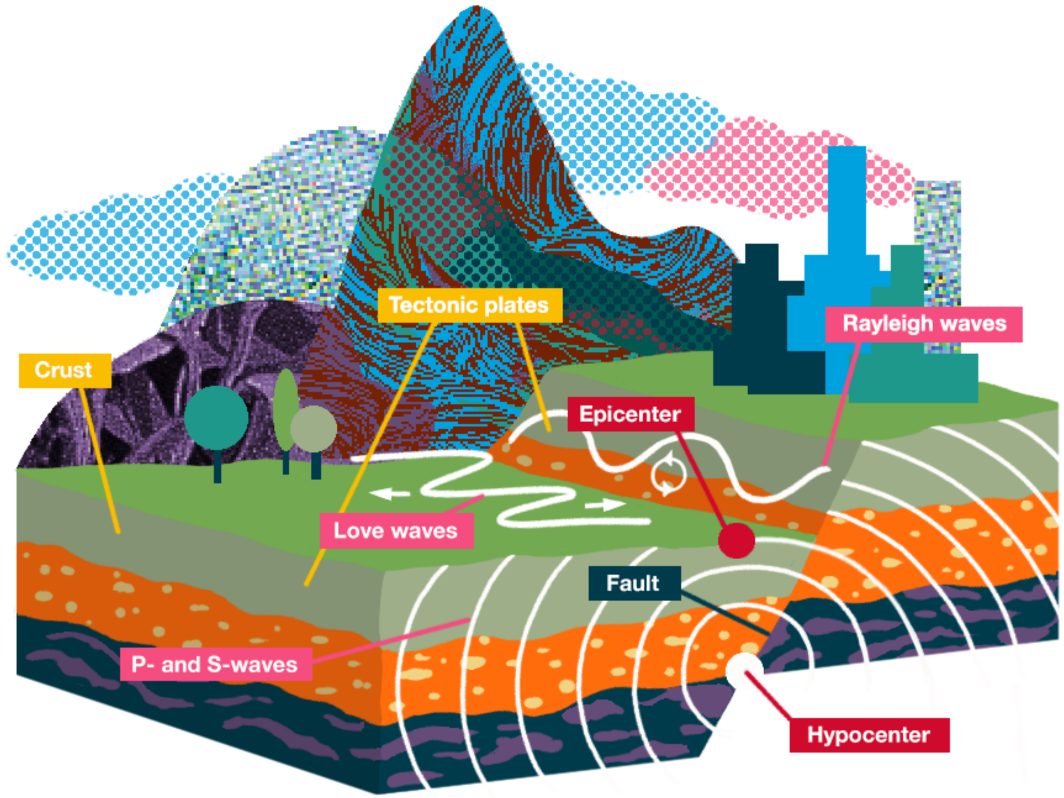
Earthquake basics

Why do we need to learn geology and geomorphological aspects?

1. Observing the geological changes at the ground surface,
2. Analyzing the symphony of earthquake vibrations recorded on seismographs and
3. Monitoring the tectonic changes in the Earth's crust by surveying it repeatedly, using land survey techniques for many years, and now using satellites.
4. Additionally, laboratory experimental results on how rocks behave at the depths and temperatures where earthquakes form.

Earthquake

An earthquake is the shaking caused by the rupture (breaking) and subsequent displacement of rocks (one body of rock moving with respect to another) beneath Earth's surface.



Fault: A surface across which two blocks can move relative to each other.

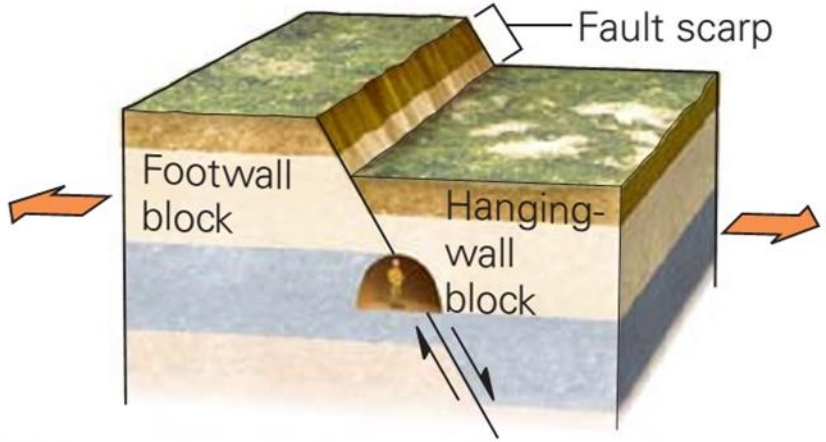
Focus: The location on a fault where earthquake rupture initiates.

Hypocentre: The calculated position of an earthquake focus.

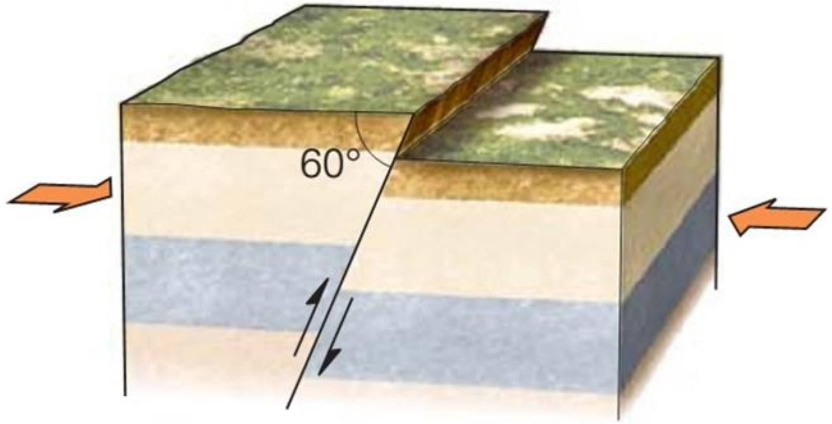
Epicentre: That point on the Earth's surface directly above the hypocentre.

Magnitude: A measure of the strength of an earthquake, as determined by seismographic.

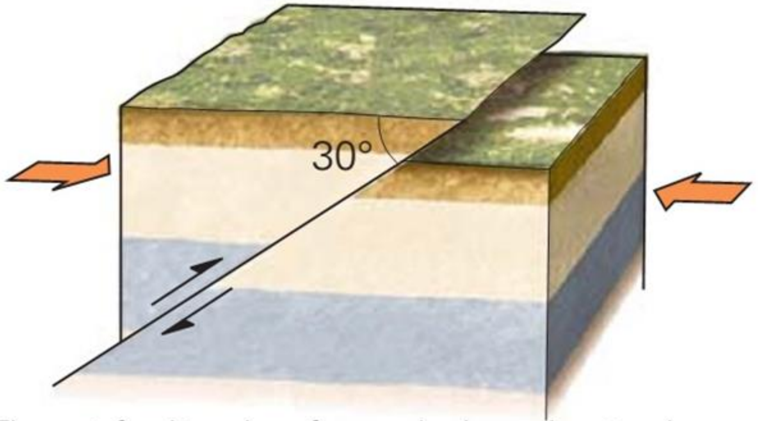
Fault: A surface across which two blocks can move relative to each other.



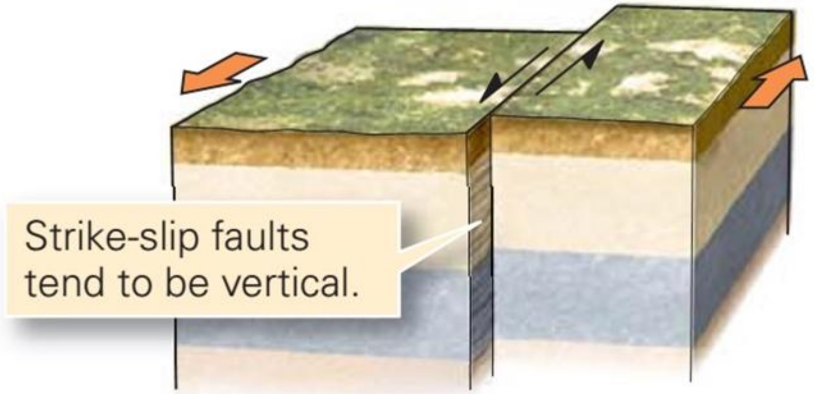
(a) Normal faults form during extension of the crust. The hanging wall moves down.



(b) Reverse faults form during shortening of the crust. The hanging wall moves up and the fault is steep.



(c) Thrust faults also form during shortening. The fault's slope is gentle (less than 30°).



(d) On a strike-slip fault, one block slides laterally past another, so no vertical displacement takes place.

Earthquake

An **earthquake** is a trembling or shaking of the ground caused by the sudden release of energy stored in the rocks beneath the Earth's surface.

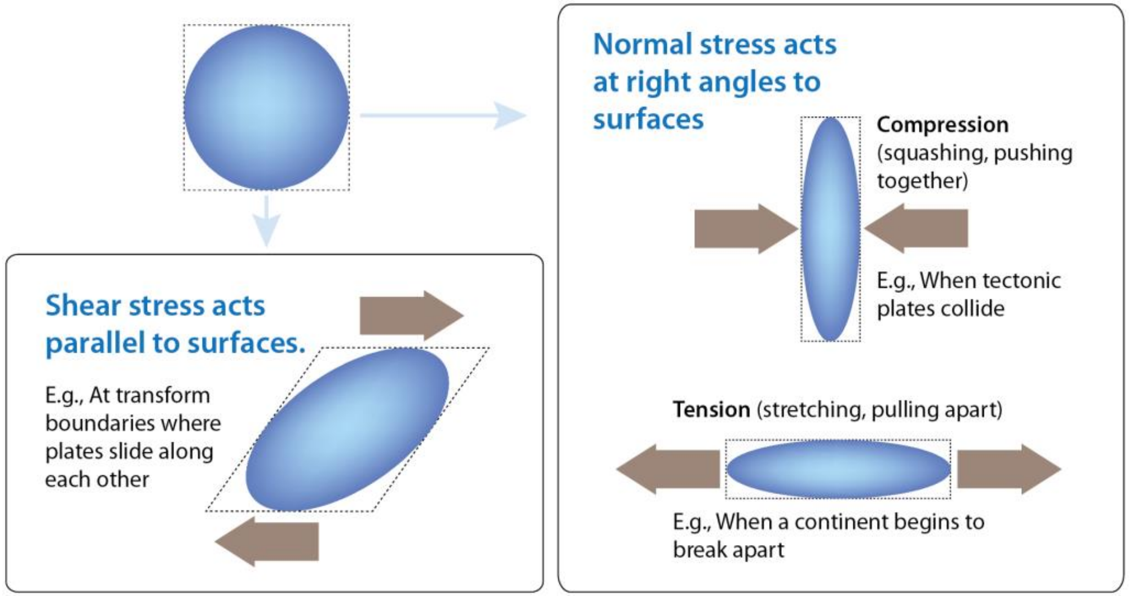
- Tectonic forces within the Earth produce stresses on rocks that eventually exceed their elastic limits, resulting in brittle failure.

Energy is released during earthquakes in the form of **seismic waves.**

- Released from a position along a break between two rock masses (fault).

Elastic rebound theory - earthquakes are a sudden release of strain progressively stored in rocks that bend until they finally break and move along a **fault.**

- **Stress** is force-adjusted for the area over which it is distributed.
- **Strain** is the change in shape that happens when rocks are deformed by stress.



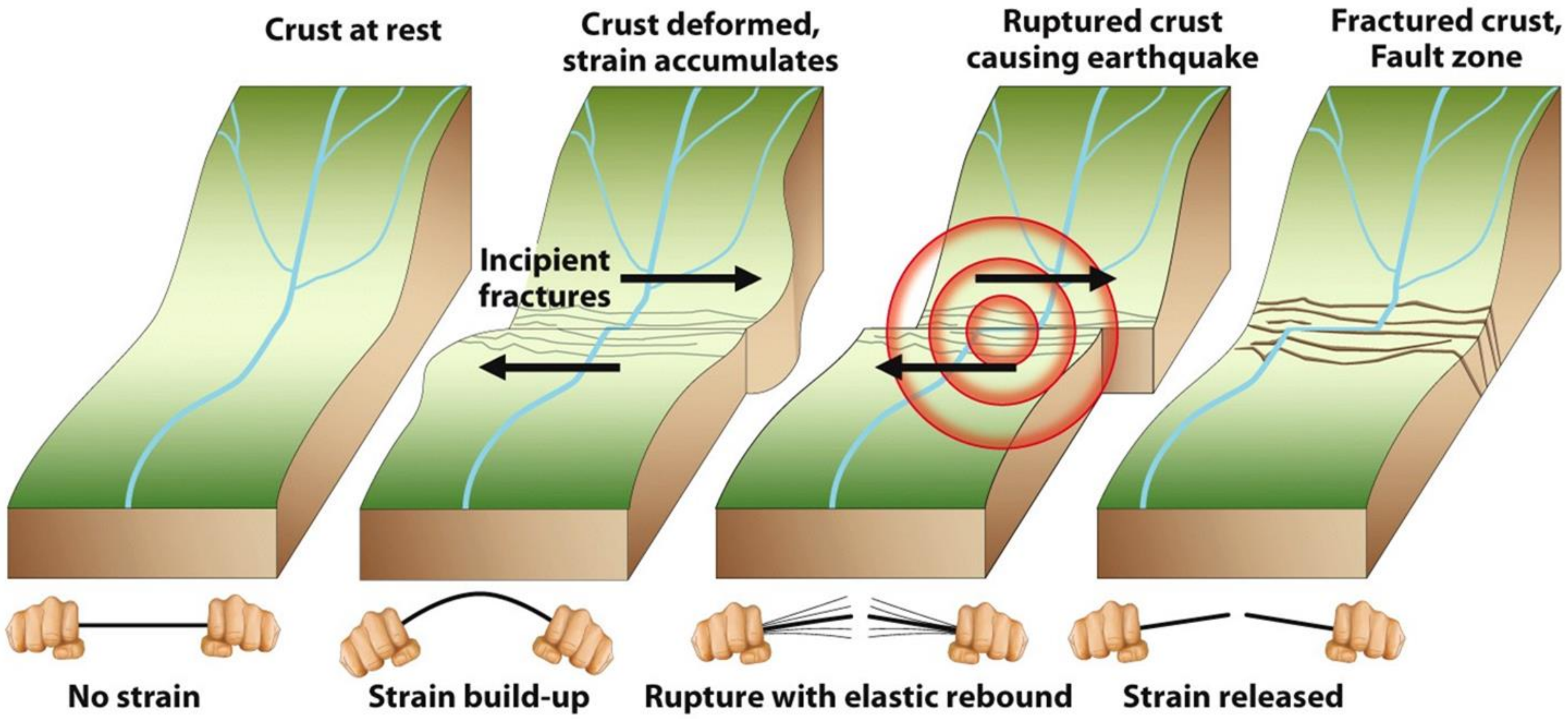
Rocks can be affected by normal stress (compression and tension) or shear stress.

Stresses fall into two categories: **normal stress** acts at right angles to a surface, and **shear stress** acts parallel to a surface.

Normal stress is subdivided into **compression** when the stresses are squeezing a rock, and **tension**, when stress pulls it apart.

Elastic strain is a reversible strain. Rocks snapping back to their original shape undergo elastic rebound.

The permanent deformation is called **plastic strain**.


Crust at rest
Crust deformed, strain accumulates
Ruptured crust causing earthquake
Fractured crust, Fault zone
Incipient fractures
No strain
Strain build-up
Rupture with elastic rebound
Strain released

Body waves

Travel through the earth.

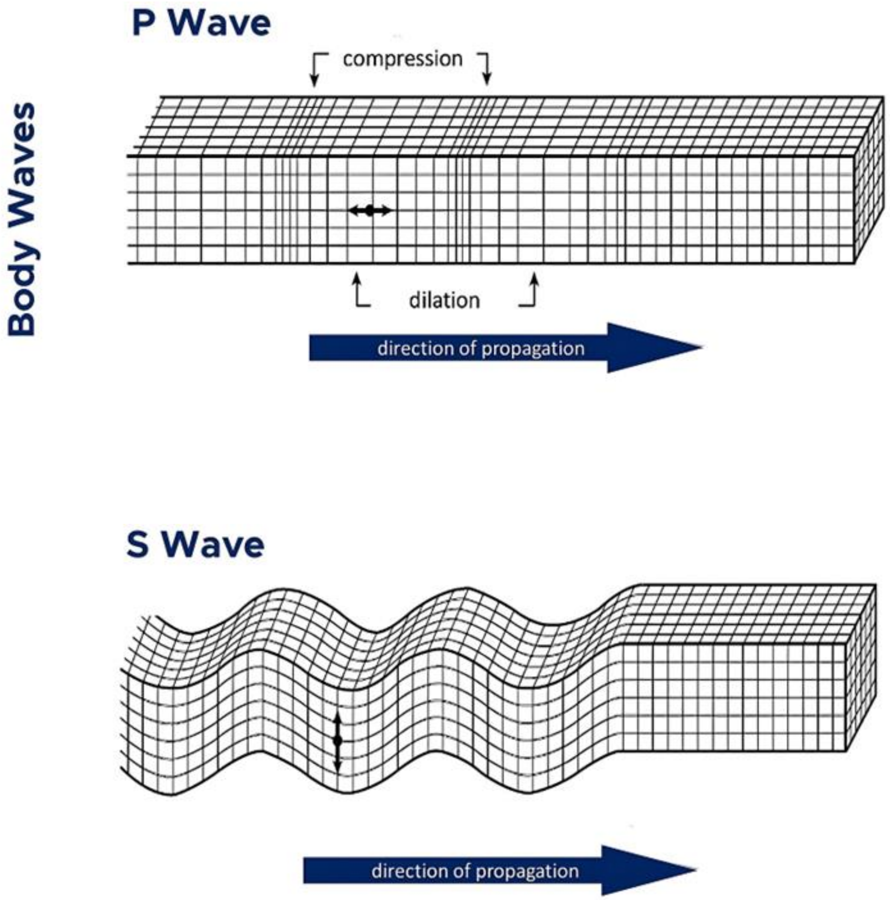
They have 2 types have different motions:

Primary (P) waves

- Particle motion is parallel to the wave direction
- Travel fastest (arrive first)
- Travel through solid or fluid

Secondary (S) waves

- Particle motion is perpendicular to wave direction
- Travel slightly slower
- Only travel through solid



Surface Waves

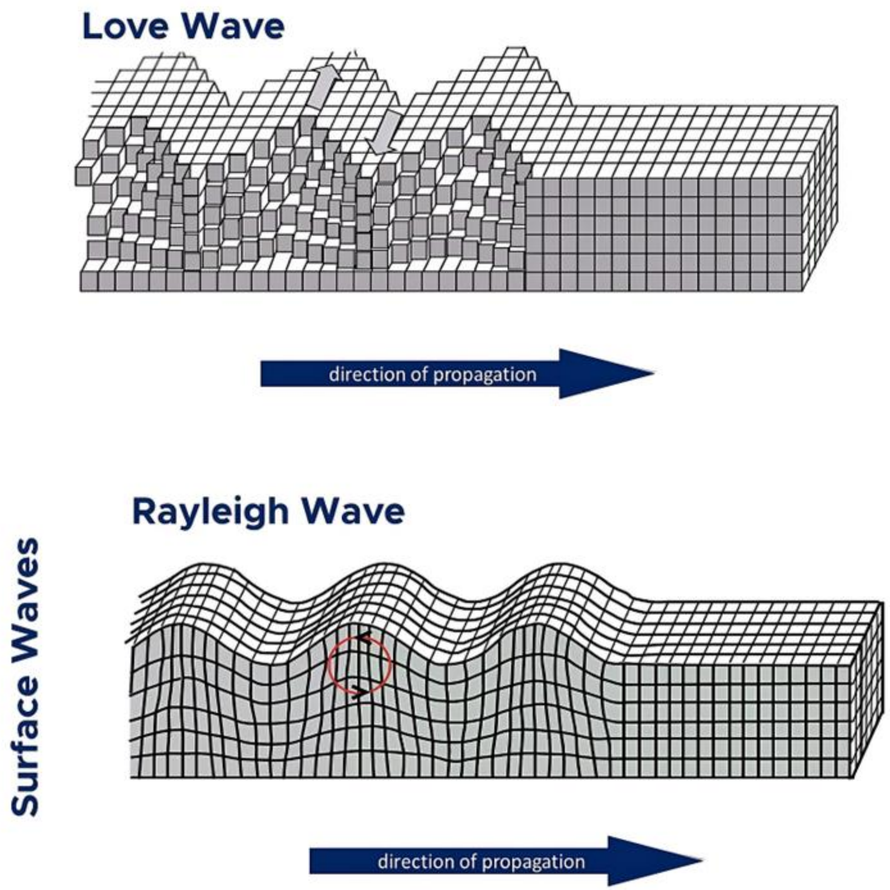
The slowest type of seismic waves produced by earthquakes

Love waves - side-to-side motion of the ground surface

- Can't travel through fluids

Rayleigh waves - ground moves in an elliptical path opposite the direction of wave motion

- Extremely destructive to buildings



Measuring Earthquakes

Seismometers - used to measure seismic waves

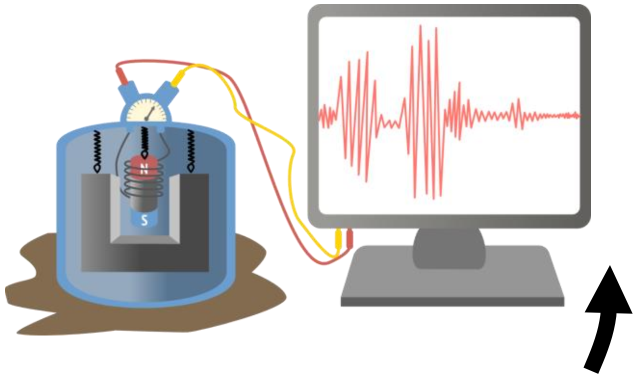
Seismographs - recording devices used to produce a permanent record of the motion detected by seismometers

Seismograms - permanent paper (or digital) records of the earthquake vibrations

- Used to measure the earthquake strengths

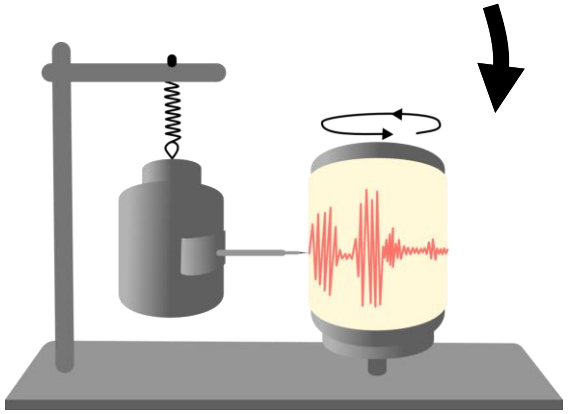
Seismograph

Measures horizontal motion (P waves)



Modern seismograph

Old fashioned seismograph



Locating earthquake

P- and S-waves leave earthquake focus at the same time.

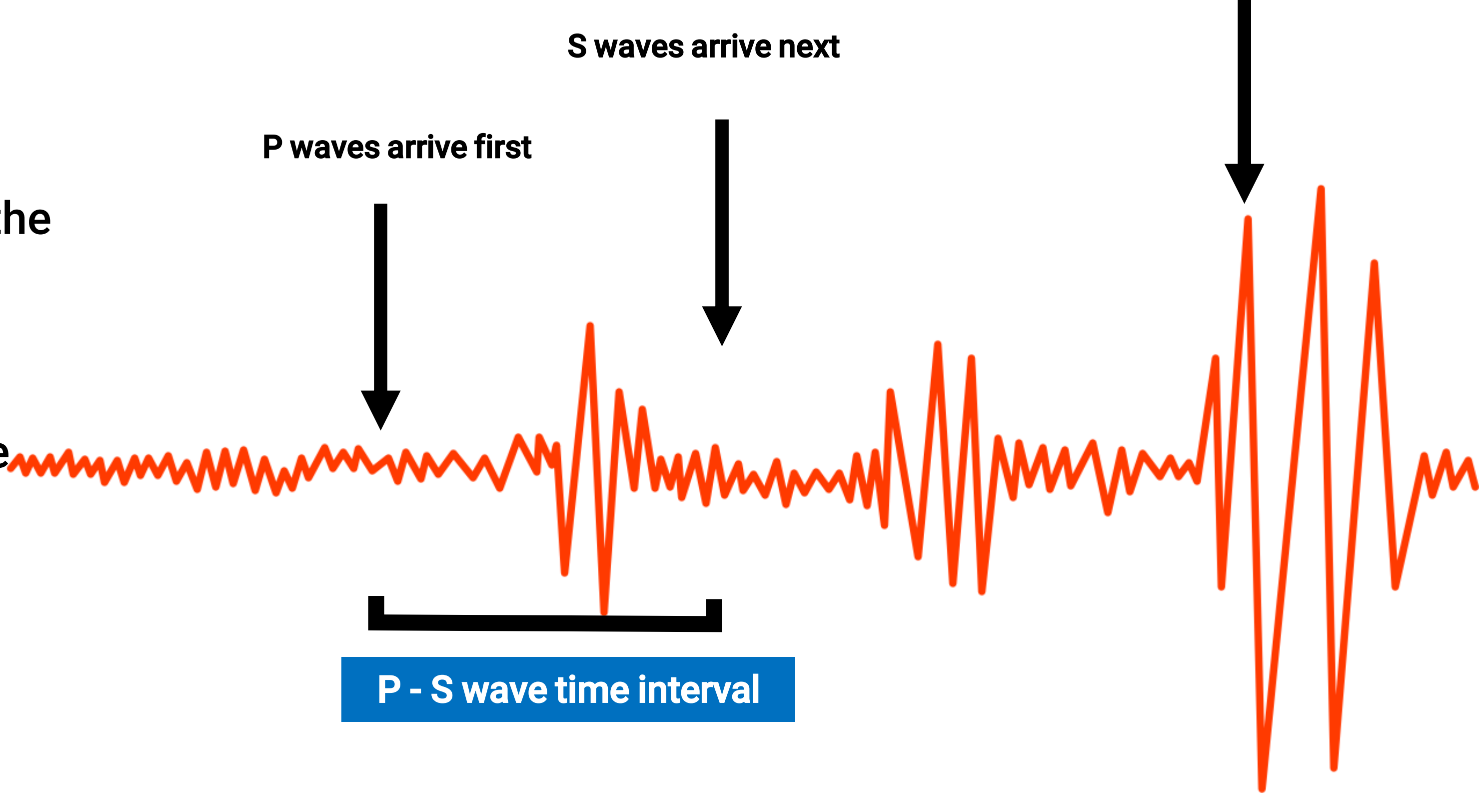
P-wave gets farther and farther ahead of the S-wave with distance and time from the earthquake.

Travel-time curve - used to determine the distance to focus.

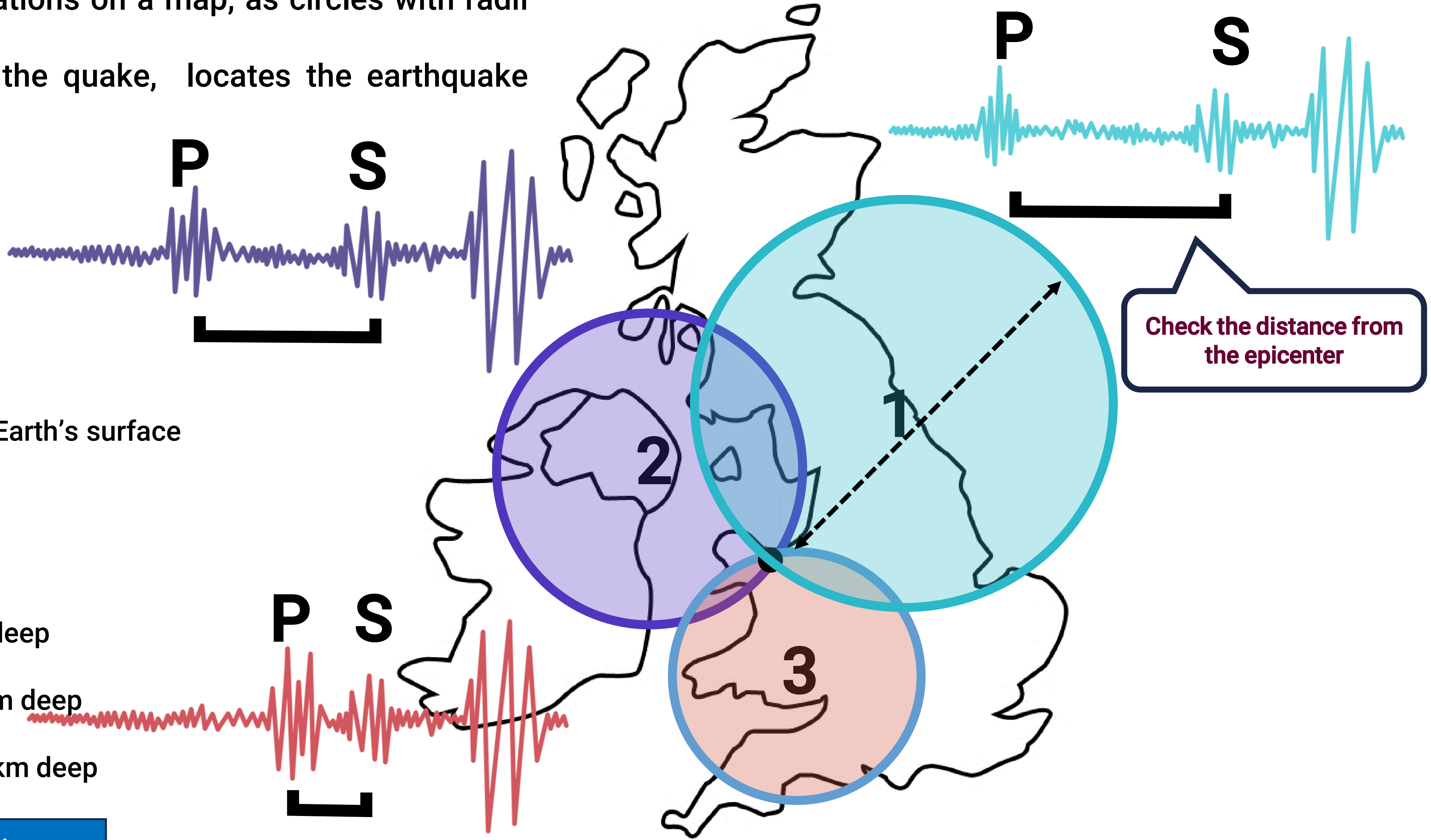
- based on the time between the first P- and S-wave arrivals

Seismograph

Measures horizontal motion (P waves)



Plotting distances from 3 stations on a map, as circles with radii equaling the distance from the quake, locates the earthquake **epicenter.**



The depth of focus beneath the Earth's surface can also be determined.

Shallow focus	0-70 km deep
Intermediate focus	70-350 km deep
Deep focus	350-670 km deep

Does not cause much damage

Measuring the “size” of earthquakes

Intensity

A measure of the effects an earthquake produces (on both structures and people)

Modified Mercalli scale

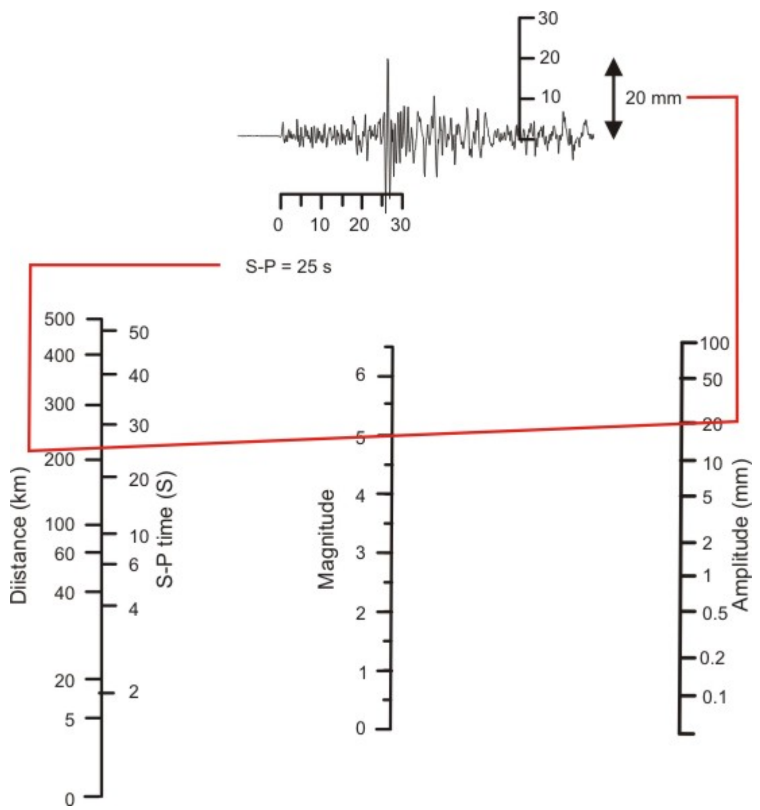
Magnitude

A measure of the amount of energy released by an earthquake

Richter scale

–Moment magnitude – a more objective measure of energy released by a major earthquake

–The uses rock strength, fault rupture surface area, and movement amount.



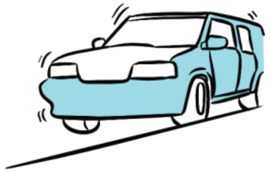
Modified Mercalli Intensity (MMI)

Not felt except by very few.

I	Not Felt

Felt only by a few persons at rest, especially on upper floors of buildings.

II	Weak



Felt indoors, though many people do not recognize it as an earthquake. Standing cars may rock slightly.

III	Weak

Felt indoors by many, outdoors by few. Dishes and windows are disturbed.

IV	Light

Felt by nearly everyone, many awakened if at night. Dishes and windows are broken.

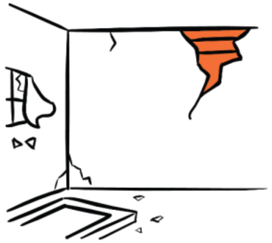
V	Moderate

Felt by all; many frightened. Some heavy furniture moved. Damage is slight.

VI	Strong

Slight to moderate damage in ordinary construction. Some chimneys broken.

VII	Very Strong

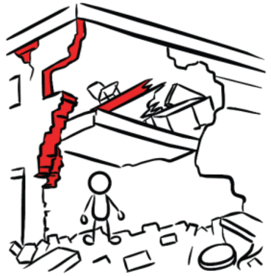


Considerable damage to ordinary construction. Chimneys, columns, and walls may fall.

VIII	Severe

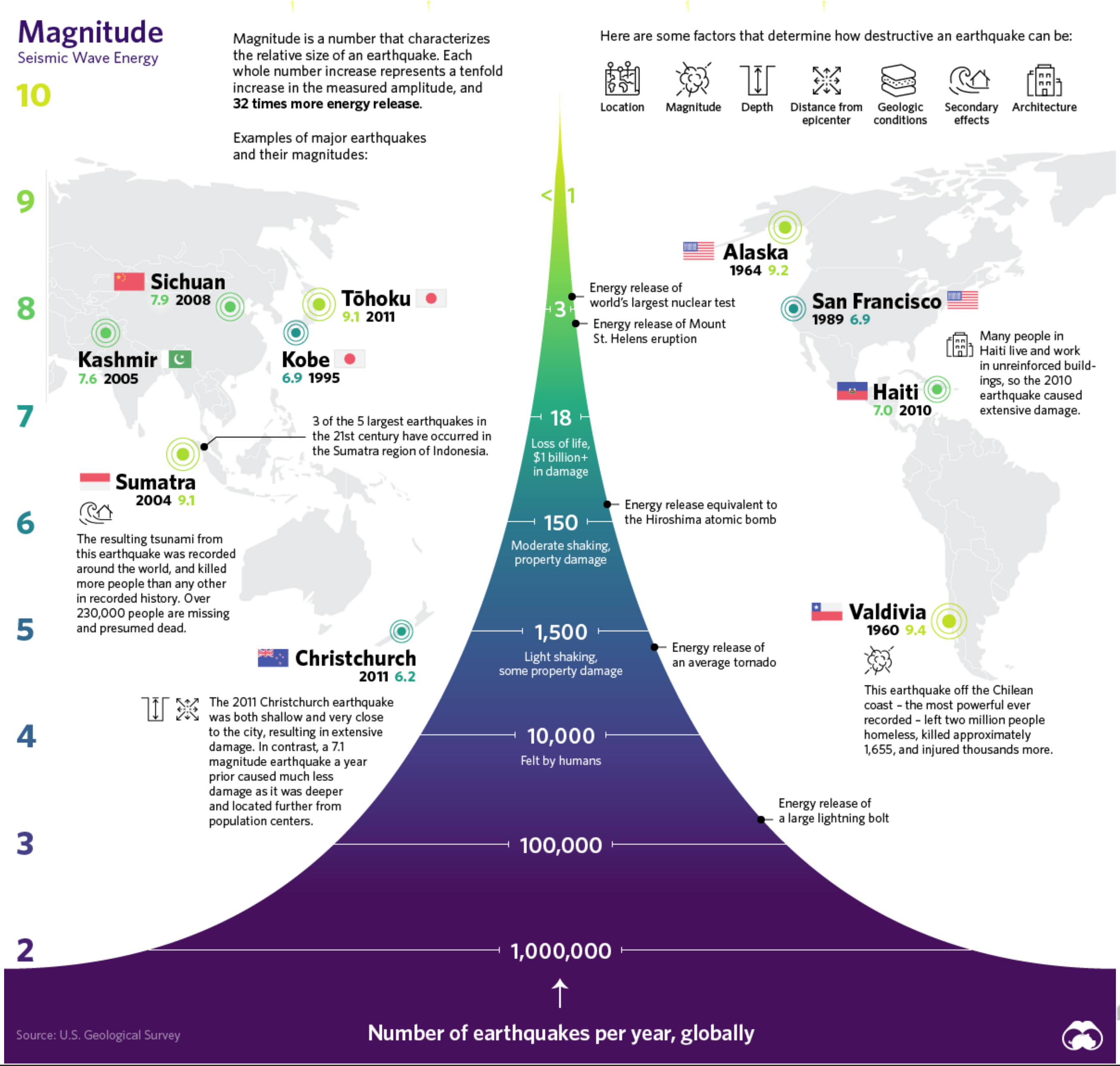
Damage is great in substantial buildings, with partial collapse. Buildings shifted off foundations.

IX	Violent

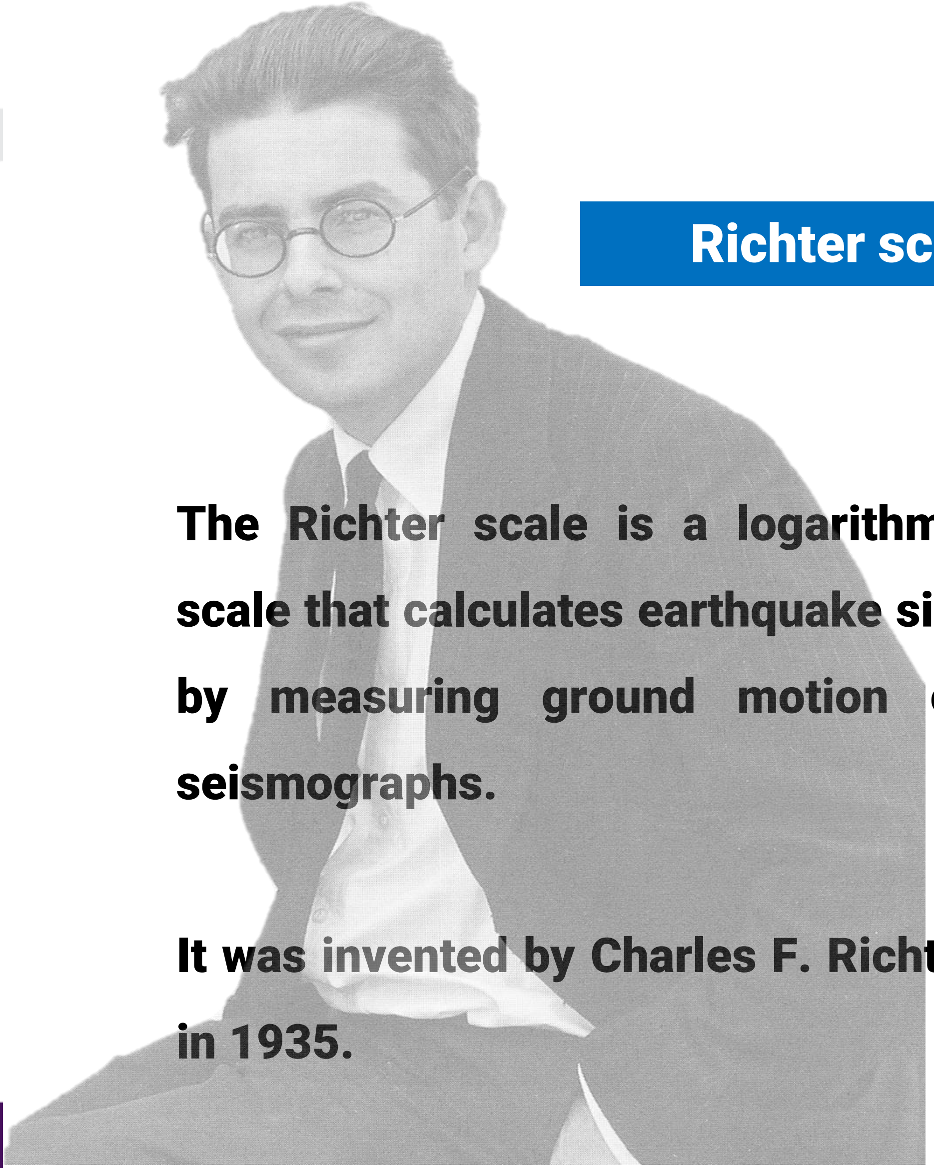


Some well-built wooden structures destroyed; most masonry and structures are destroyed.

X+	Extreme



Richter scale



The Richter scale is a logarithmic scale that calculates earthquake size by measuring ground motion on seismographs.

It was invented by Charles F. Richter in 1935.

Measuring the fault size

Rupture Size and Offset

Rupture size

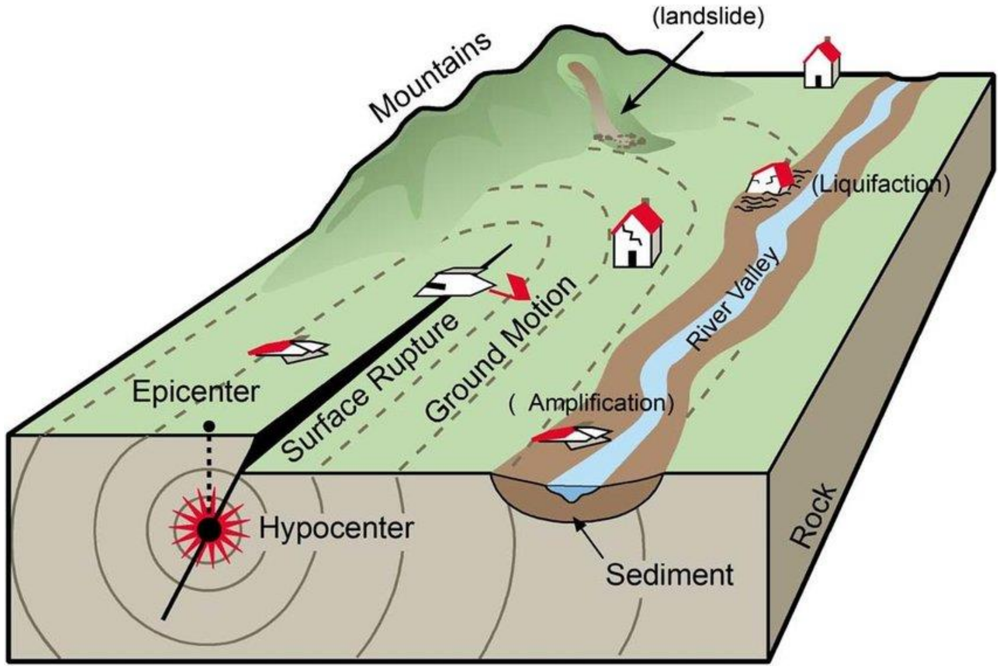
Another measure of earthquake size is the area of the fault that slipped during the earthquake.

During large earthquakes, the part of the fault that ruptures may be hundreds of kilometers long and 10s of kilometers deep.

Smaller earthquakes rupture smaller portions of the fault. Thus, the area of the rupture is an indicator of the earthquake size.

Offset

That is, how far did the two sides move? Small earthquakes have slips of less than a centimeter; large earthquakes move the rocks about 10-20 meters.



Effects of earthquake

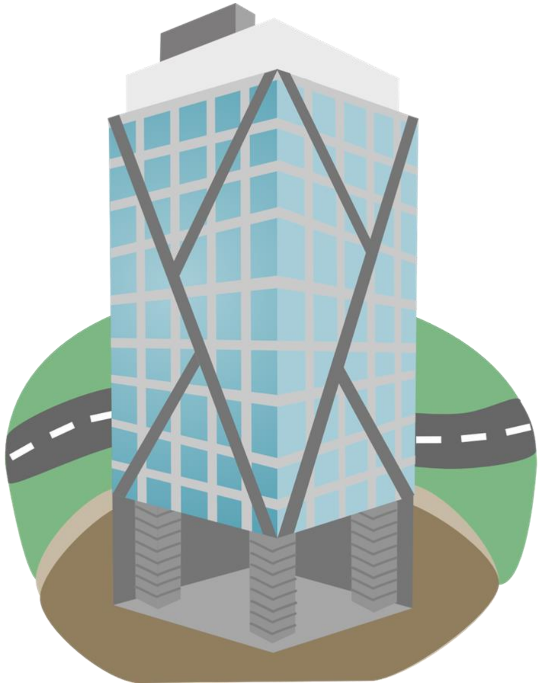
Earthquakes produce several effects, all of which can cause loss of property and human life.

Ground motion is the familiar trembling and shaking of the land during an earthquake - it can topple buildings and bridges.

Fire is a problem after earthquakes because of broken gas, water mains, and fallen electrical wires.

Landslides can be triggered by ground shaking, particularly in larger quakes.

Liquefaction occurs when water-saturated soil or sediment sloshes like a liquid during a quake.



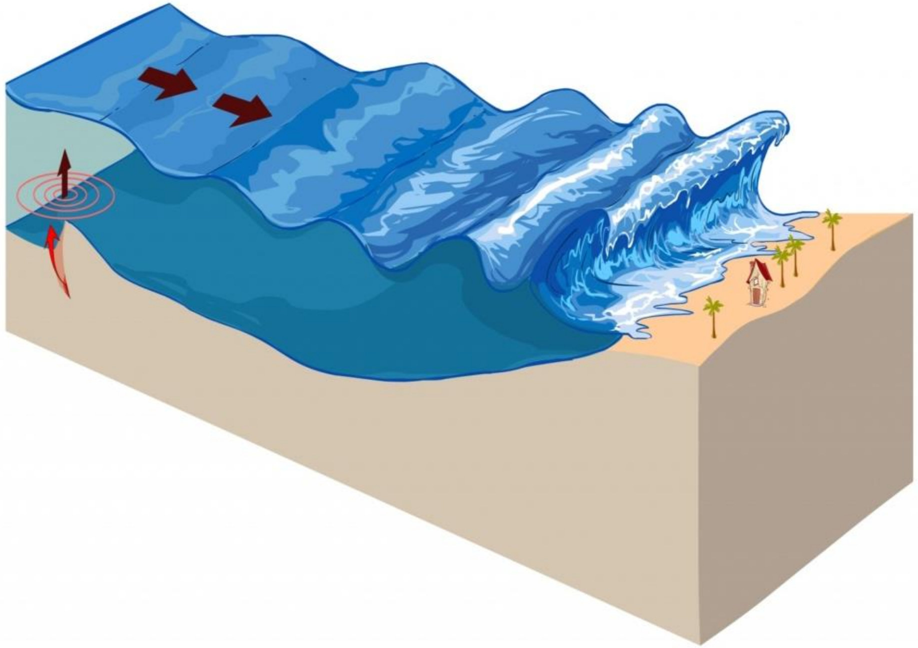
Tsunami

Tsunami (seismic sea waves) - very large sea waves caused by sudden upward or downward movement of the sea floor during submarine earthquakes generally produced by magnitude 8+ earthquakes (“great” earthquakes - e.g., 9.3 Indonesia, 2004)

May also be generated by large undersea landslides or volcanic explosions.

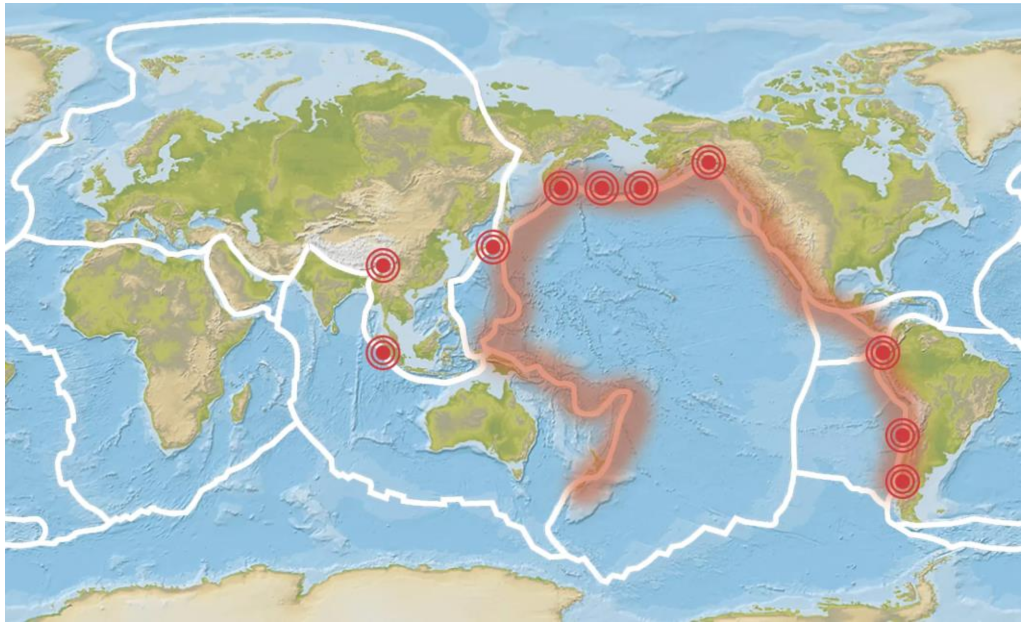
Travel across the open ocean at speeds of >700 km/hr.

Reach great heights in coastal areas with gently sloping seafloor and funnel-shaped bays.



World earthquake distribution

- Most earthquakes occur in narrow geographic belts which mark tectonic plate boundaries
- Most important concentrations in circum-Pacific and Mediterranean-Himalayan belts
- Shallow-focus earthquakes common along the crests of mid-oceanic ridges
- Nearly all intermediate- and deep-focus earthquakes occur in Benioff zones
  - inclined seismic activity associated with descending oceanic plate at subduction zones)



Earthquakes and plate tectonics

Plate interactions along tectonic plate boundaries cause earthquakes.

Plate boundaries are identified and defined by earthquakes

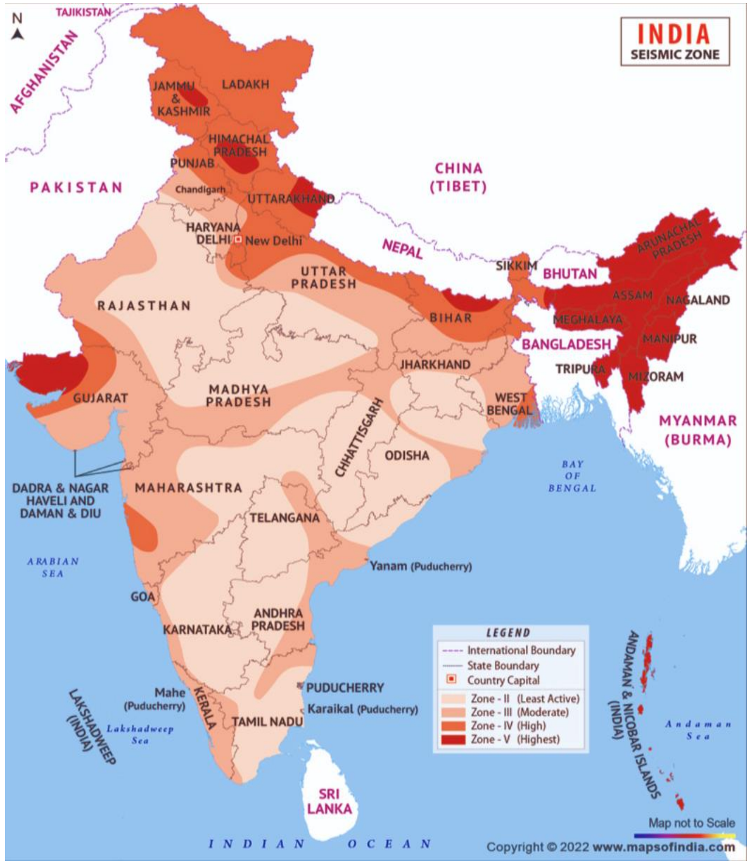
Earthquakes occur at each of the three types of plate boundaries: divergent, transform, and convergent

At divergent boundaries, tensional forces produce shallow-focus quakes on normal faults

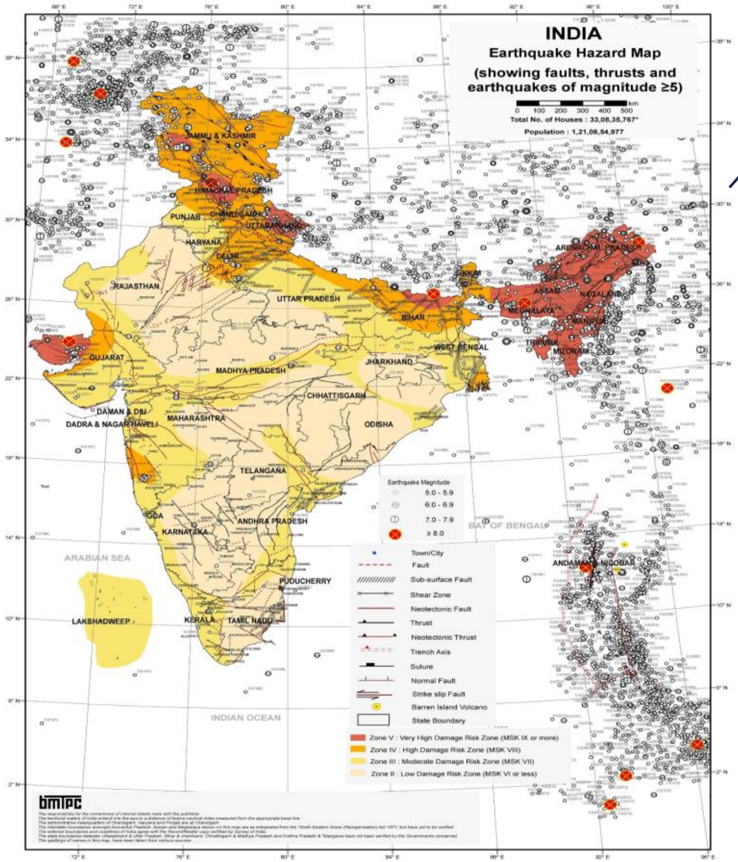
At transform boundaries, shear forces produce shallow-focus quakes along strike-slip faults

At convergent boundaries, compressional forces produce shallow- to deep-focus quakes along reverse faults

Earthquake in the context of India



Classification of India into seismic zones



Earthquake hazard map of India

59% of India's land area is liable to seismic hazard damage.

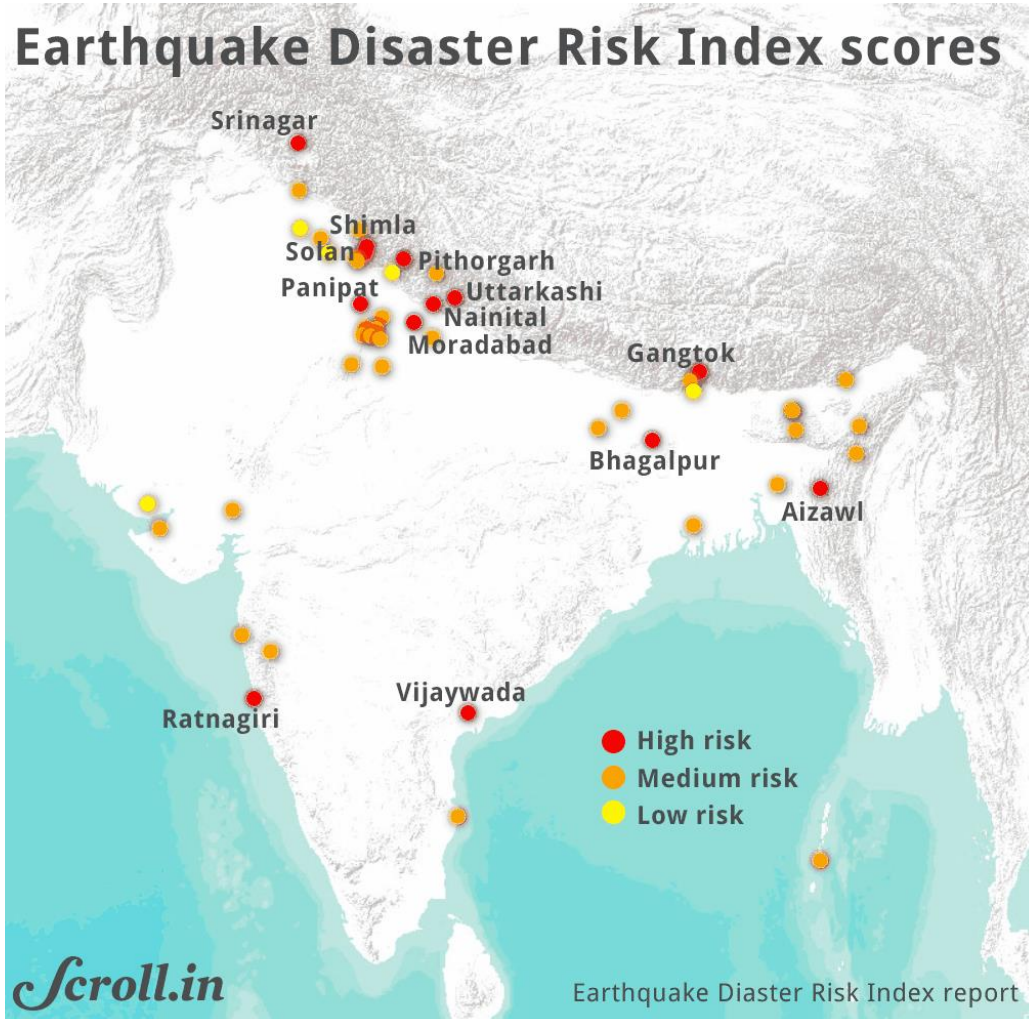
Hazard map

Published in 1962 by the Bureau of Indian Standards (BIS).

What are hazard maps used for?

- Building Codes
- Bridges
- Insurance rates
- Business and land planning
- Waste disposal facility
- Funds for disaster

Earthquakes in India



Several moderate earthquakes,

1. Bihar-Nepal border (M6.4) in 1988,
2. Uttarkashi (M6.6) in 1991,
3. Killari (M6.3) in 1993,
4. Jabalpur (M6.0) in 1997,
5. Chamoli (M6.8) in 1999,
6. Bhuj (M6.9) in 2001,
7. Sumatra (M8.9) and Kashmir (M7.6) in 2005

– 40,000 fatalities due to the collapse of buildings.

– Significant reasons for such enormous casualties are low earthquake awareness and poor construction practices..

Source: https://scroll.in/article/946222/these-13-indian-cities-face-the-greatest-danger-from-earthquakes-according-to-a-new-disaster-index
https://ndma.gov.in/sites/default/files/PDF/Reports/EDRI_Report_final.pdf

References

Reference materials for each slide are quoted at the right end of the PowerPoint.