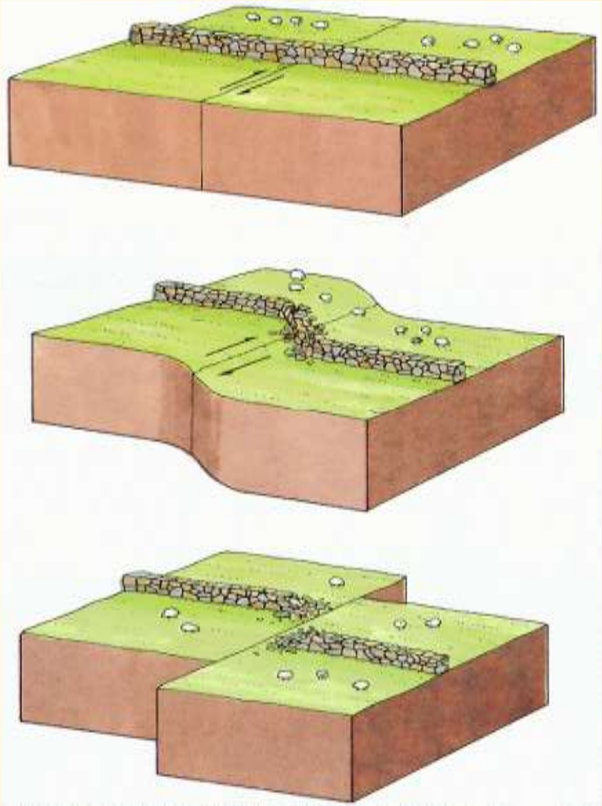
Chapter 7: Seismology

7.1 Nature of Earthquakes

- When forces act along a fault line, rock masses **bend** and **compress** until there is enough stored energy to overcome friction between the rock masses.
- This energy is quickly released as kinetic energy, causing the fault to give or slip to readjust its position, resulting in an **earthquake**.
- The sudden vibrational movement of an earthquake may be so slight that it can only be detected by instruments, or it can release enough energy to cause the ground to visibly **shake** and buildings to collapse.



Causes of earthquakes:

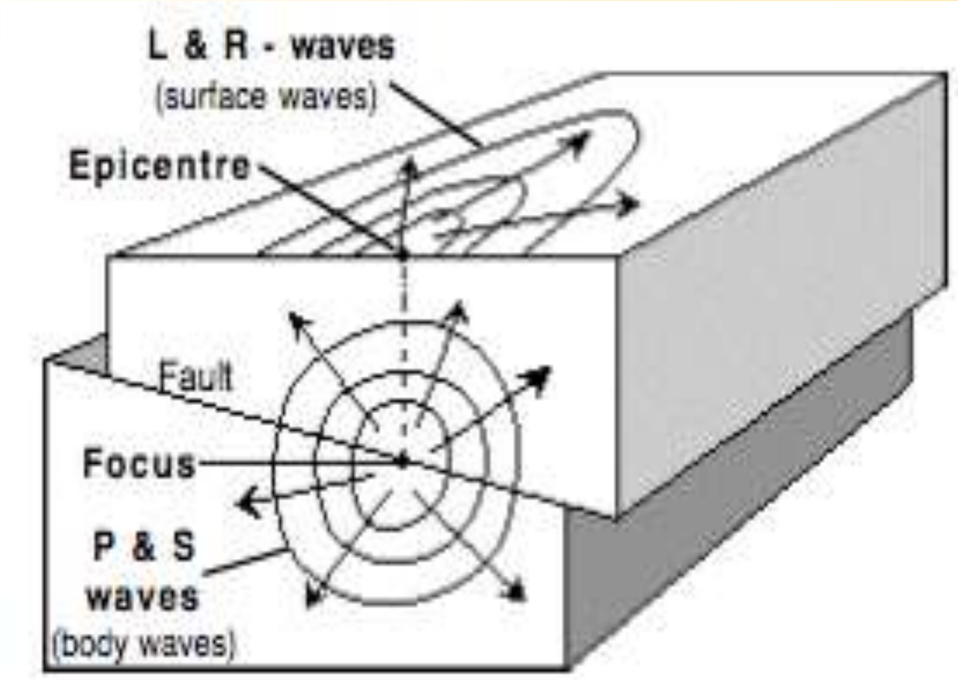
- **Tectonic:** sudden movement along a structural **fault** in the Earth. This is the root cause of the majority of earthquakes.
- **Volcanic:** internal build-up of magma prior to an **eruption** may trigger local earthquakes
- **Anthropogenic:** the building of large dams, fracking, and nuclear testing can all contribute to unnatural local **pressures** on underlying rocks.
- **Miscellaneous:** meteorite impacts, tidal effects, and cave-ins can, in **rare** cases, cause earthquakes.

- On a worldwide basis, earthquake activity tends to fall in very definite **zones**.

- Many of these zones, however, are under the **oceans** and are consequently go unnoticed except by scientists.

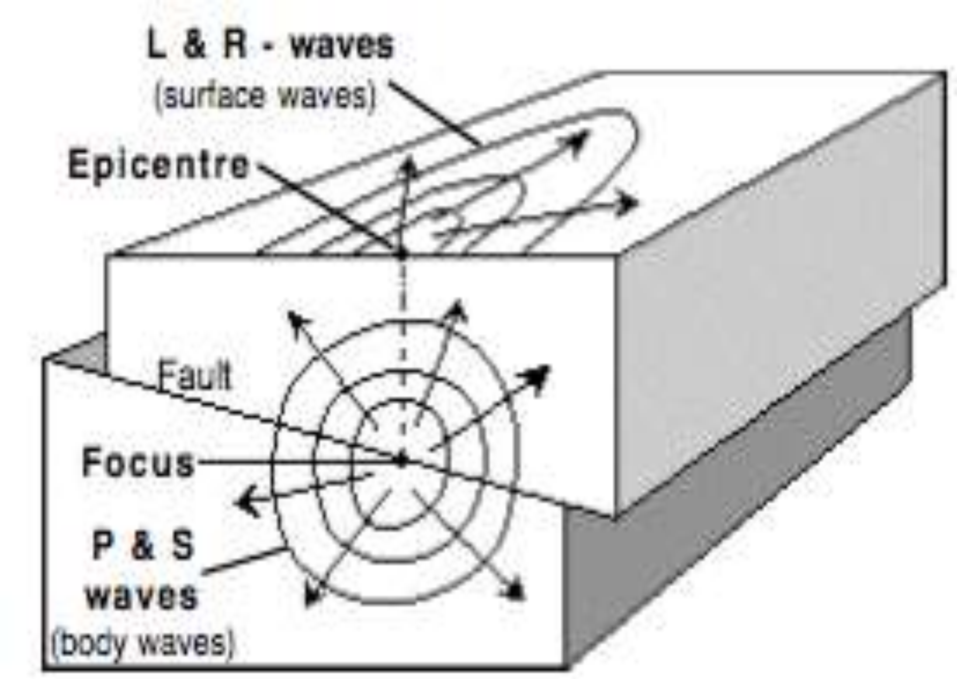
Fig. 21-10 major earthquake zones around the world.

- The actual shock wave from an earthquake spreads out from the **focus** deep underground.
- The energy spreads out in all directions through the bedrock as **P** and **S waves**.
- The point at which these shock waves reach the surface, directly above the focus, is the **epicenter**.

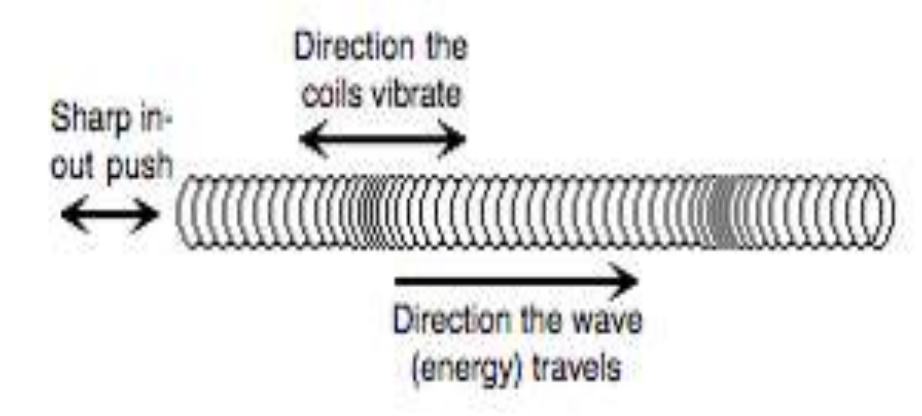


- At the epicenter, **L** and **R waves** form, spreading out across the surface.

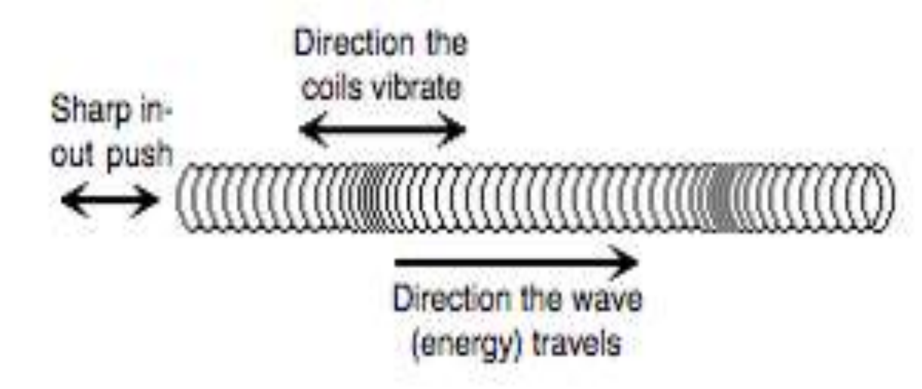
- Each type of seismic wave has different **characteristics**, and can be categorized as either a **compressional** wave or **transverse** wave.



- Compressional waves are rather like sound waves in that the rock particles vibrate back and forth in the **same** direction as the wave.

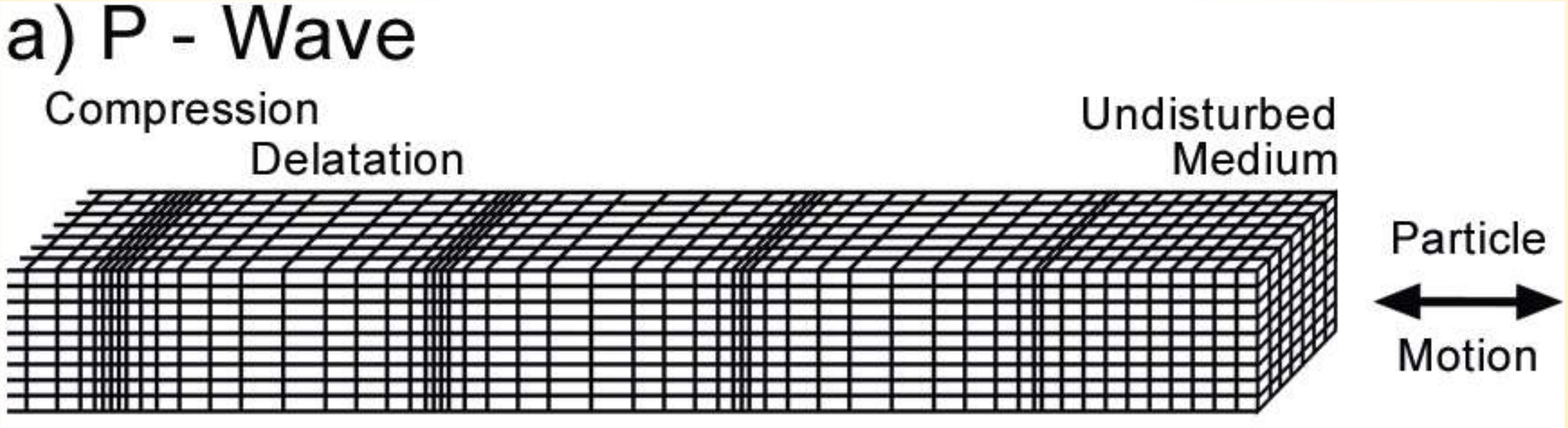


- Transverse waves are like the waves that can be created in a stretched string or wire in which the particles vibrate at **right angles** to the direction of motion.

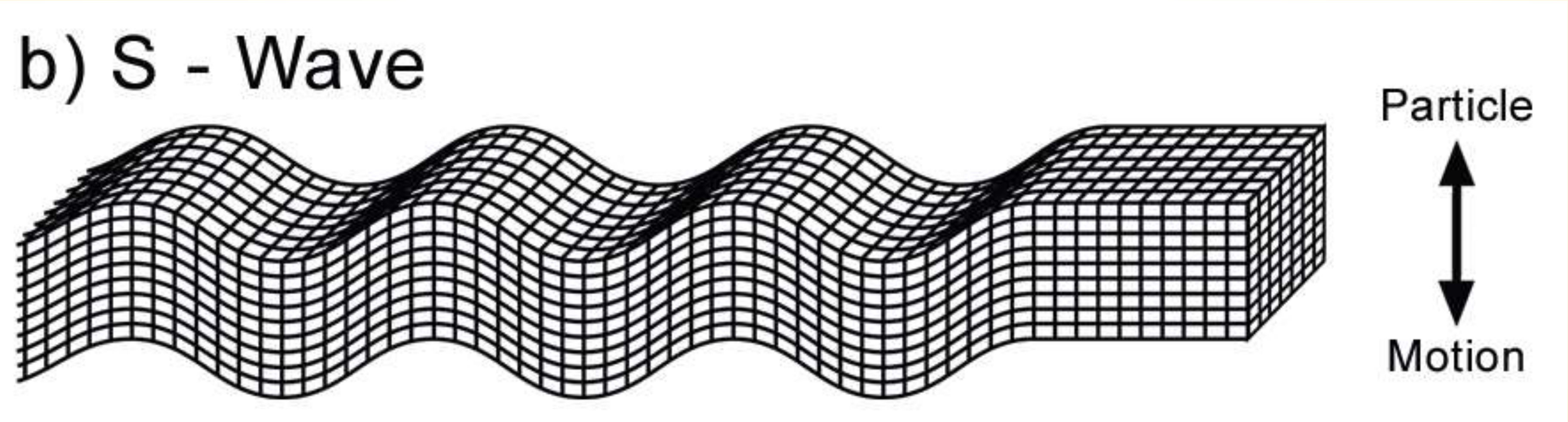


Types of Seismic Waves:

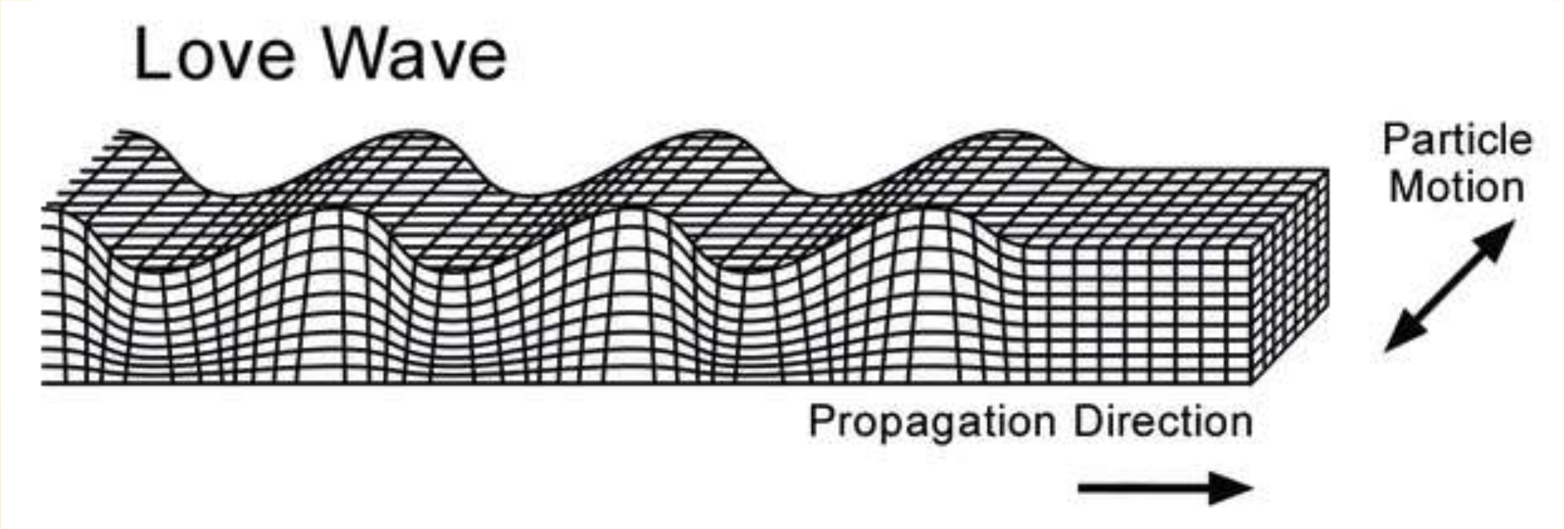
- **P-waves:** compressional waves that travel through both solids and **liquids**. These are the fastest waves, traveling at speeds from 5.5 to 13 km/s depending on the type of rock. They arrive at the recording station **first**.



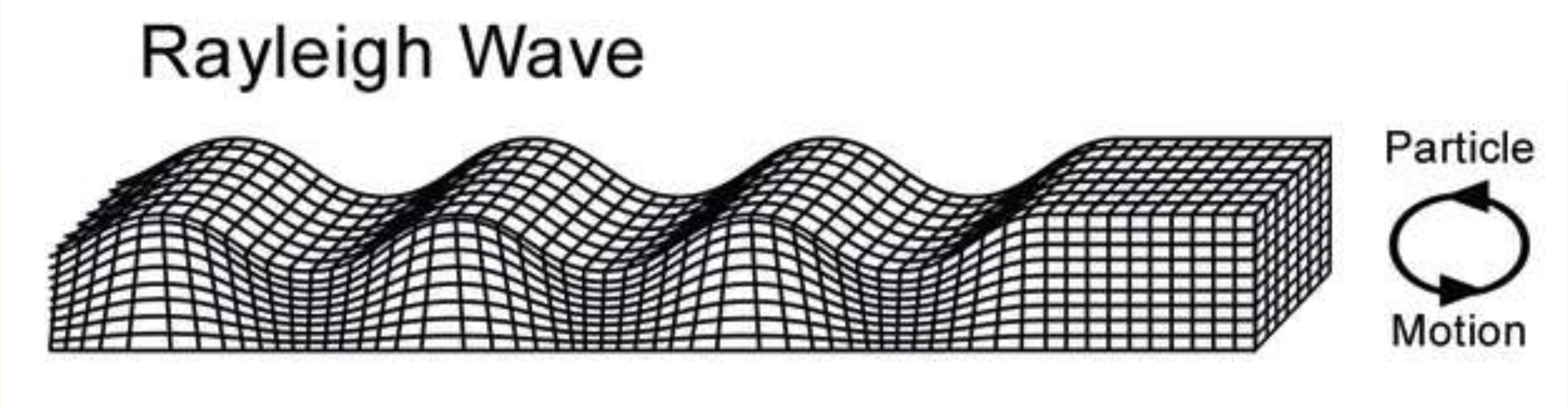
- **S-waves** -These are shear or transverse waves that only travel through **solids**. These are slower, traveling from 3 to 7 km/s, and are the **second** waves to reach the recording station.



- **L-waves** -These are long wavelength, sinuous, undulating shear waves that are confined to the **surface** of the Earth and move at about 4 km/s. They are last to reach the recording station and are generally the most **damaging** waves.

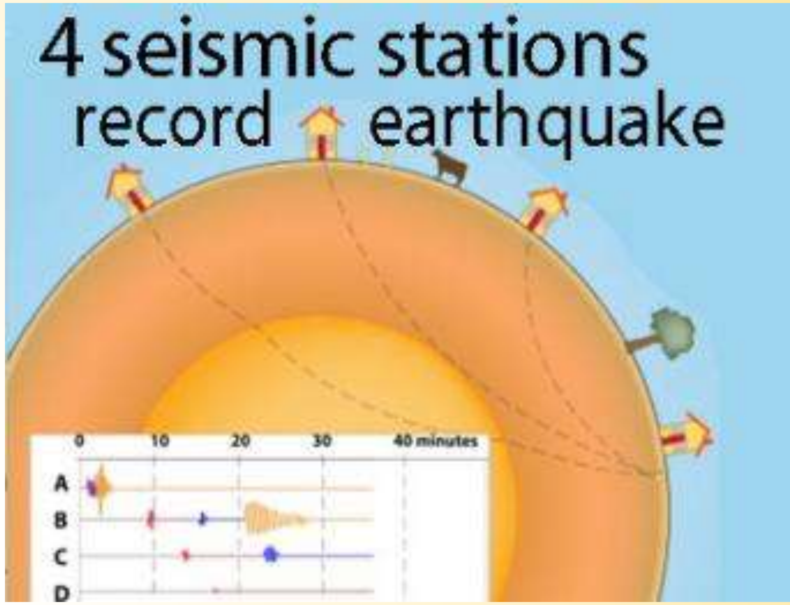


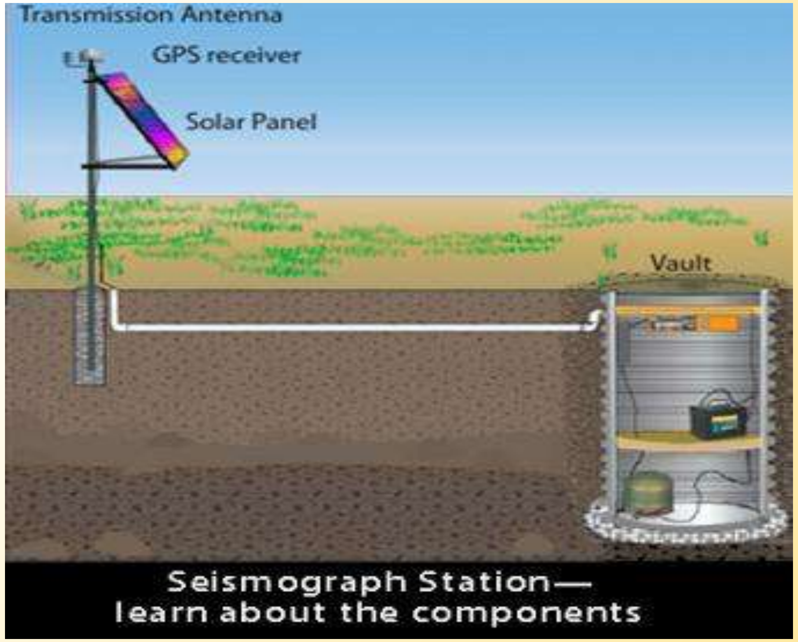
- **R-waves** -These are also surface waves that behave like a **water** wave, with both a vertical and horizontal component. The horizontal displacement is in the direction of wave travel, so they are also very damaging.



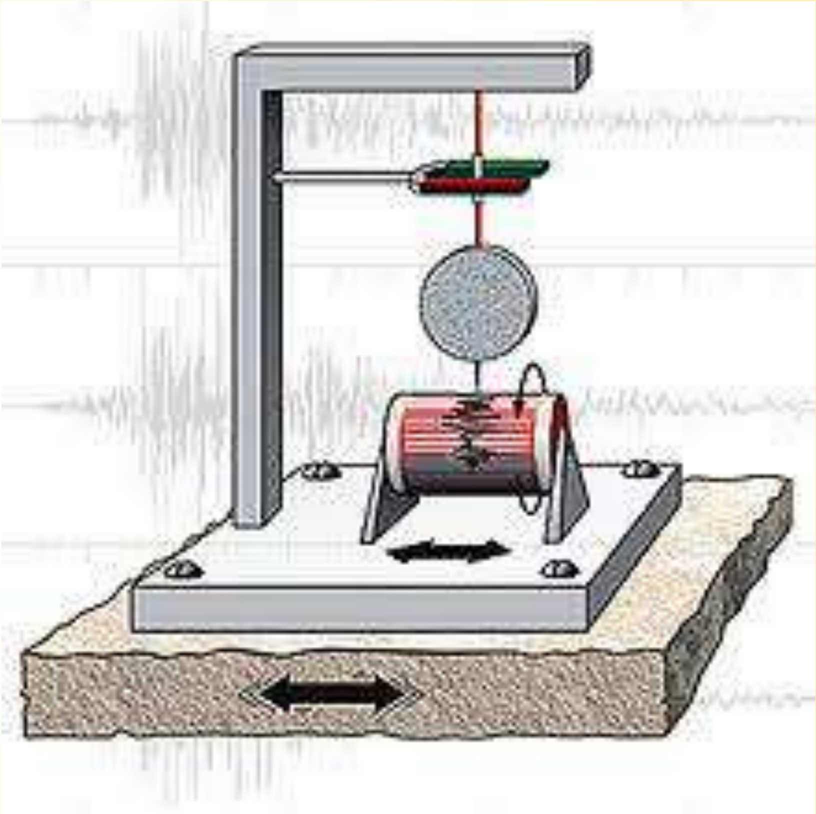
7.2 Locating an Earthquake

- When seismic waves arrive at a recording station, they are detected by an instrument called a **seismograph** **(seismometer)**
- Seismographs are anchored directly into the bedrock at the recording station.





- The device is comprised of a freely-swinging, heavy **mass** that tends to remain in place during an earthquake (due to inertia), while the **ground** moves beneath it.
- The mass is then attached to a pen and drum to **record** that movement.



- A **horizontal** motion detector has its mass on a swing arm so that it can move freely from side to side:

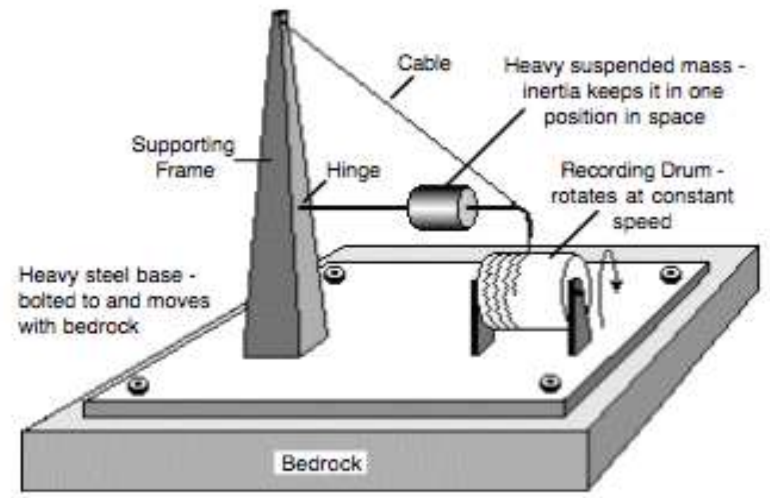


Fig. 21-4 Schematic of a horizontal ground motion detector.

- In the **vertical** motion detector, the mass is suspended from a spring so that it can move up and down:

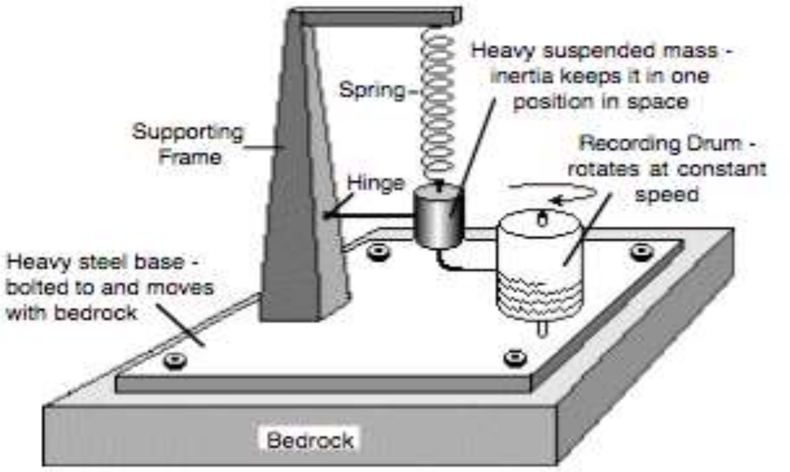
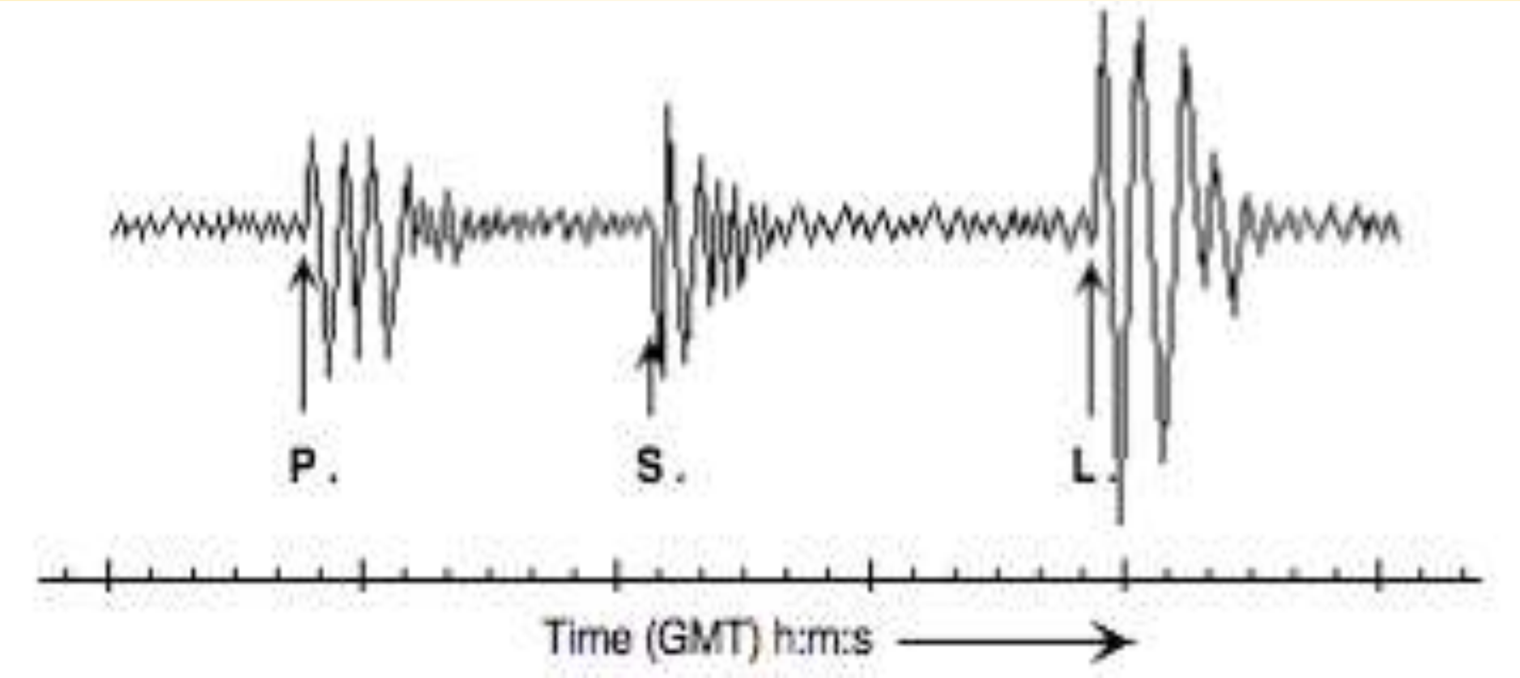
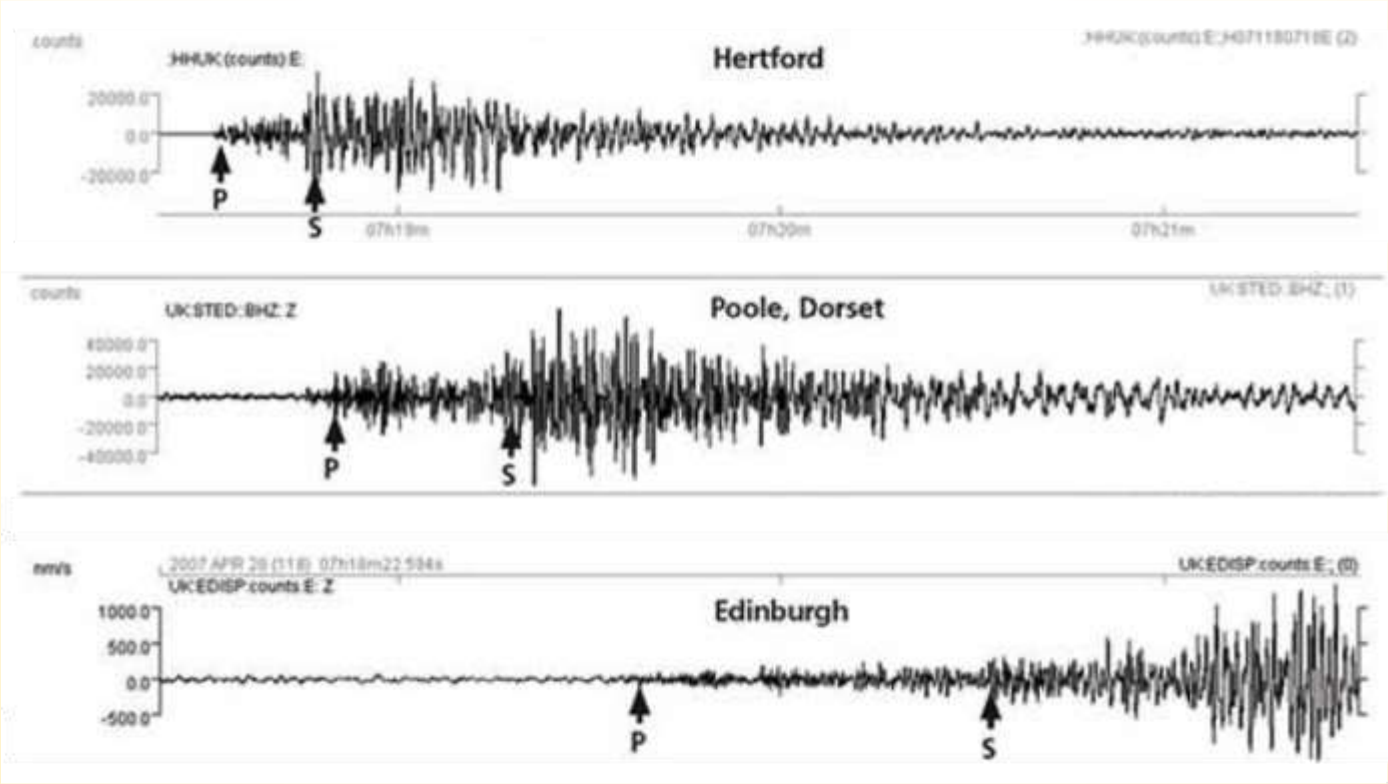


Fig. 21-5 Schematic of a vertical ground motion detector.



- The pattern of wave motion recorded on the drum is the **seismogram**.
- The **P**-waves arrive first, followed by the **S**-waves
- The **L**-waves, which create the most motion and are consequently the most **damaging**, arrive later.

- The closer the wave motions are to each other on the seismogram, the **closer** the station is to the epicenter of the earthquake.



- **P**-wave and **S**-wave arrival times can be plotted against distance from the epicenter to produce what's known as a **Distance-Time Graph**.
- If the difference in arrival times between the P-waves and S-waves is known, then this graph can be used to estimate the **distance** between the recording station to the epicenter.

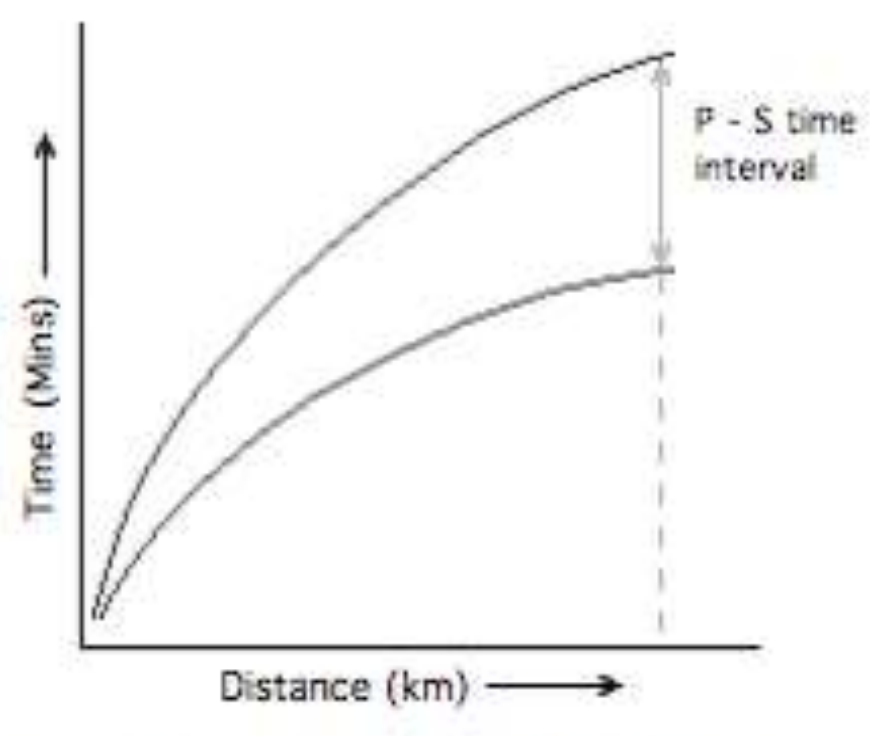


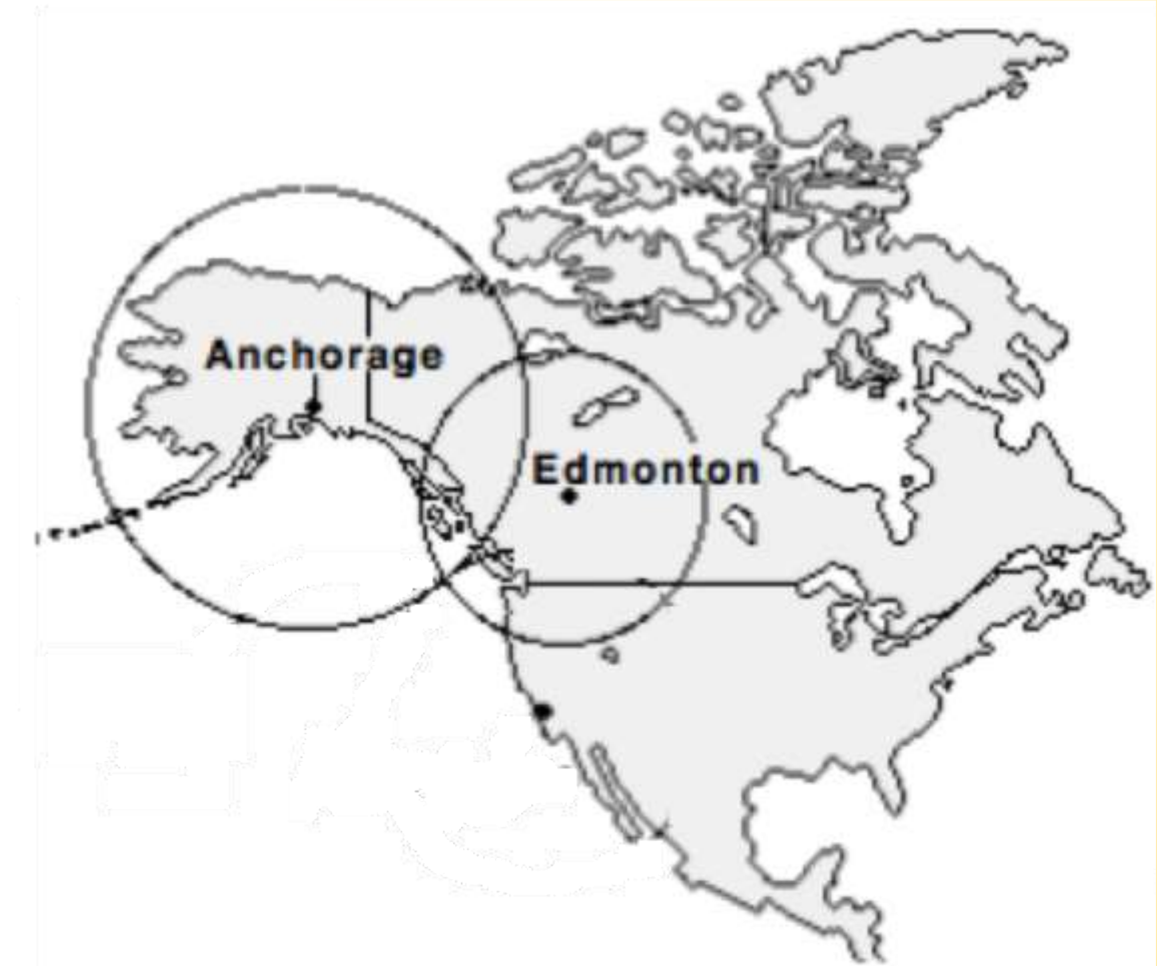
Fig. 21-B Distance – Time graph for P and S waves.

- The distance-time graph enables scientists to determine the **distance** to the epicenter, but not the **direction**.
- Using the data from a single recording station, we can only determine that the epicenter lies somewhere on a **circle** surrounding the station, with a radius equal to the distance to the epicenter.

The circle around Anchorage on the map below indicates that for this sample earthquake the ***epicenter*** *lies somewhere on that circle.*

- If the data from a seismic station in Edmonton is also used, a second distance circle can be drawn around that station.

The circles intersect at ***two*** *points, but only one of which is the actual position of the epicenter.*



- A **third** station is needed (*in this example Los Angeles*), which finally locates the epicenter as being off the coast of Vancouver Island.

- This process of locating the epicenter is called **triangulation**.

7.3 Measuring Earthquake Magnitudes

What does it mean when a scientist states that an earthquake was a magnitude 7?

- There are two scales used for indicating the size of an earthquake:
    - The **Richter Scale** for measuring the **magnitude** or **energy**
    - The more subjective **Mercali Scale** for measuring **intensity** or degree of damage.

The Modified Mercali Intensity Scale

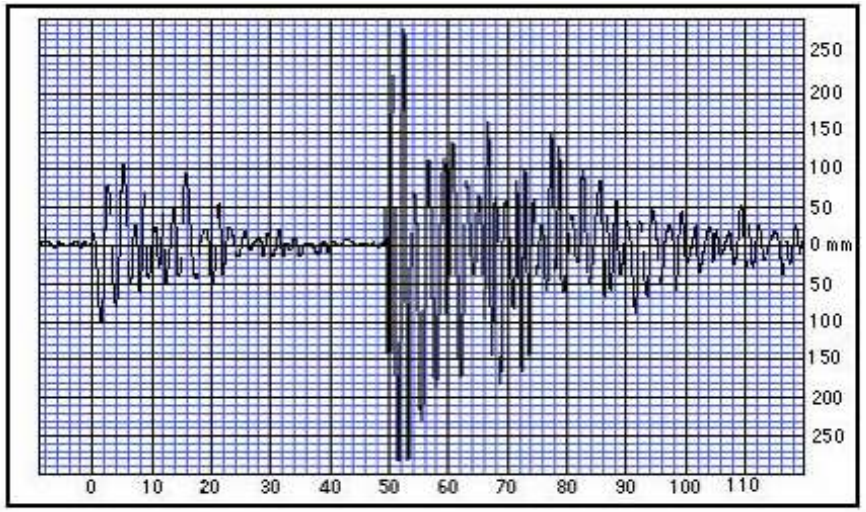
- ranges from **I** to **XII** and is a measure of the actual physical **damage** as seen on the ground.
- Since it needs detailed observations, it takes **time** to develop an intensity map around the area of an earthquake.
- The intensity effects diminish as one moves **further** away from the epicenter.

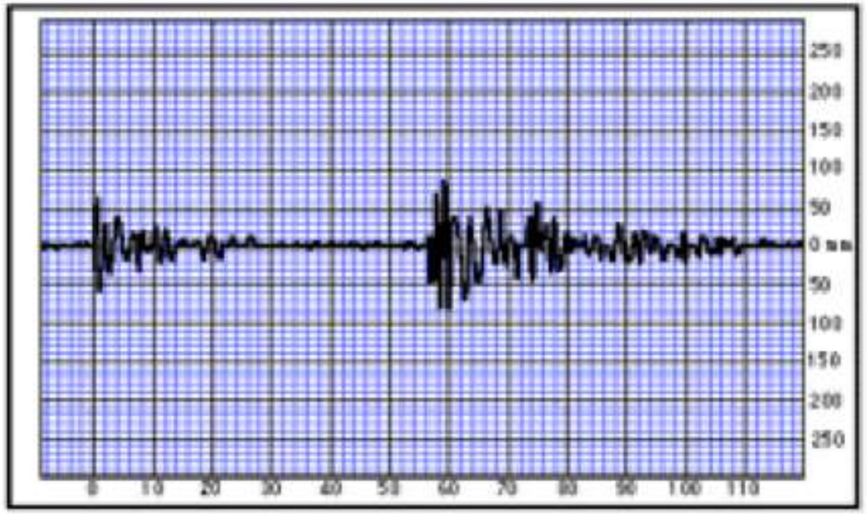
The Richter Magnitude Scale

- more common scale, measures the energy of an earthquake at its **focus**.
- The Richter Scale is based on a logarithmic scale where each scale whole number represents **ten** times the energy of the previous number.

*For example, a Richter value of 2 is not 2 x that of a 1, but rather **10** x greater, and a 4 is **100** x greater than a 2.*

- The Richter number is calculated from the maximum **deflection** of the wave pattern on the seismograph.



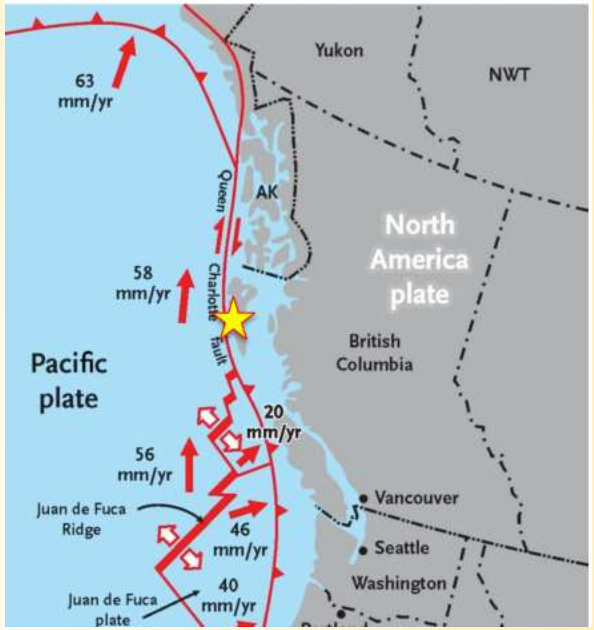


The Richter and Mercali Scales together with brief estimates of damage are compared in the table below:

Richter Magnitude	Mercali Intensity	Ground damage at epicentre
2	I – II	Usually only detected by instruments
3	III	Felt indoors
4	V	Felt by most people, slight damage
5	VI-VII	Felt by all, many frightened and run outdoors, damage minor to moderate
6	VII-VIII	Everybody runs outdoors, damage moderate to major
7	IX-X	Major damage
8+	X-XII	Total and major damage.

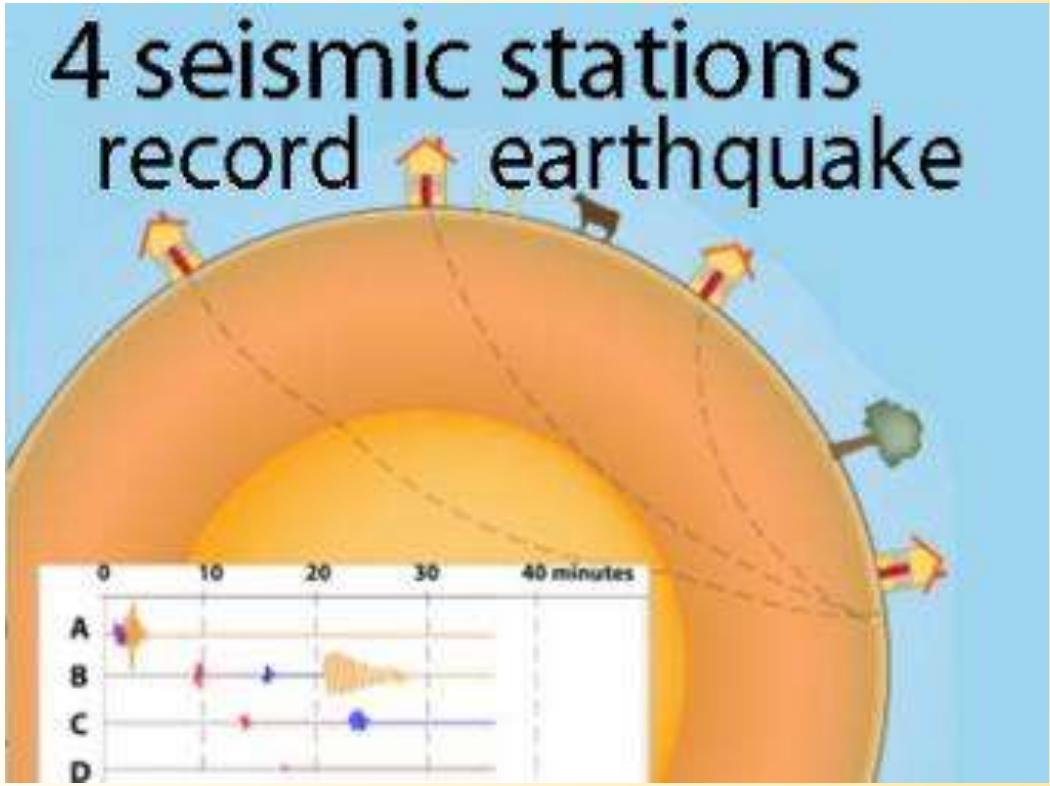
• The largest earthquake measured on the Richter scale is a **9.5** earthquake in 1960 near Valdivia, Chile.

- The highest magnitude recorded in BC so far is 8.1 on the **Queen Charlottes** fault in 1949.
- However, historical evidence suggests that the Pacific Northwest is susceptible to severe earthquakes every 300 - 500 years. On Jan. 26, 1700, an earthquake with an estimated magnitude of 9.4 occurred off the coast of southern British Columbia and north-west Washington at the **Cascadia** subduction zone.



7.4 Seismic Waves & the Internal Structure of the Earth

- The study of earthquake arrival times has led to a greater understanding of the structure of the Earth's **interior**.
- When a major earthquake occurs, the whole Earth shakes and stations around the world will detect the vibrations.



- This information has allowed scientists to determine the velocities of P-waves and S-waves at various **depths** within the earth.
- As P-waves and S-waves travel through the earth, they change **speed**, bend, or get reflected.

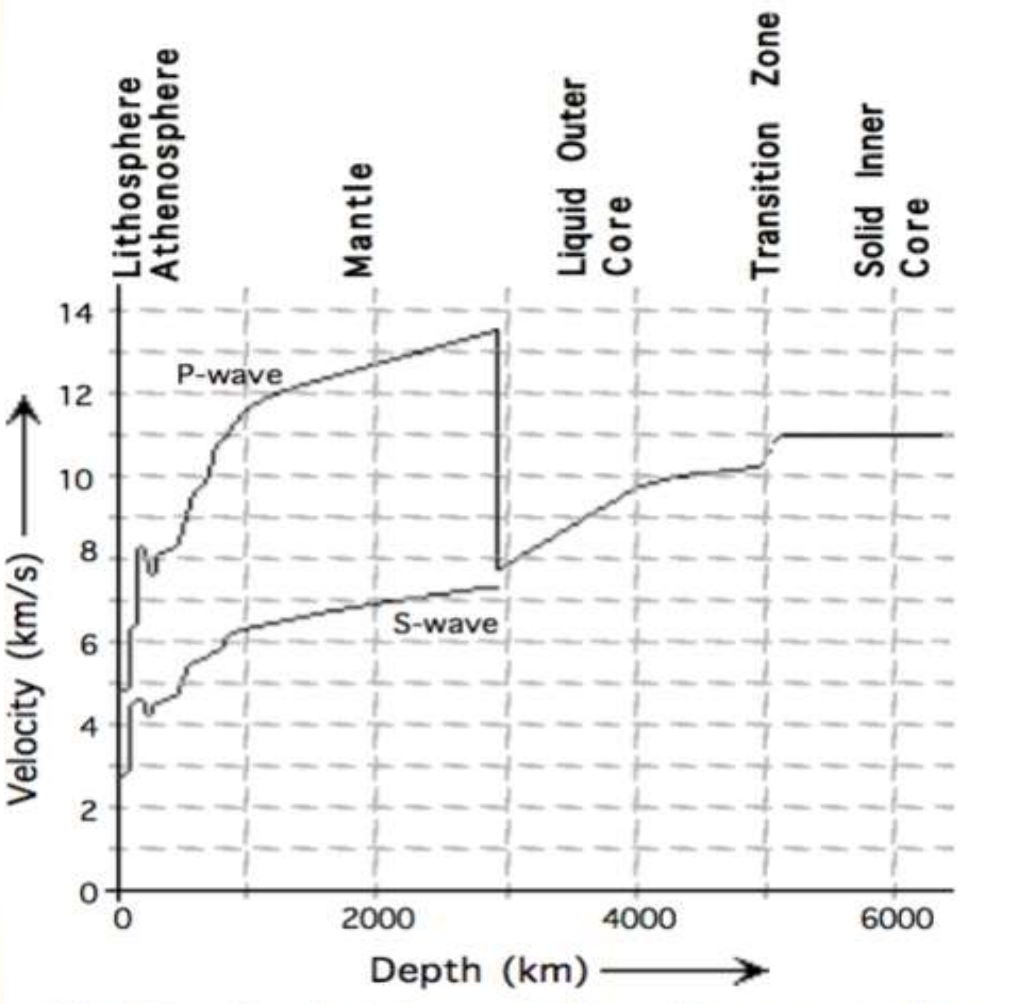


Fig. 22-1 Graph of changes in **P** and **S** wave velocities with depth.

- This indicates that the structure of the interior of the earth is not **uniform** and instead consists of a number of well-defined **zones**

- Even within the zones, speeds increase as the waves go deeper, indicating that **density** increases with depth.

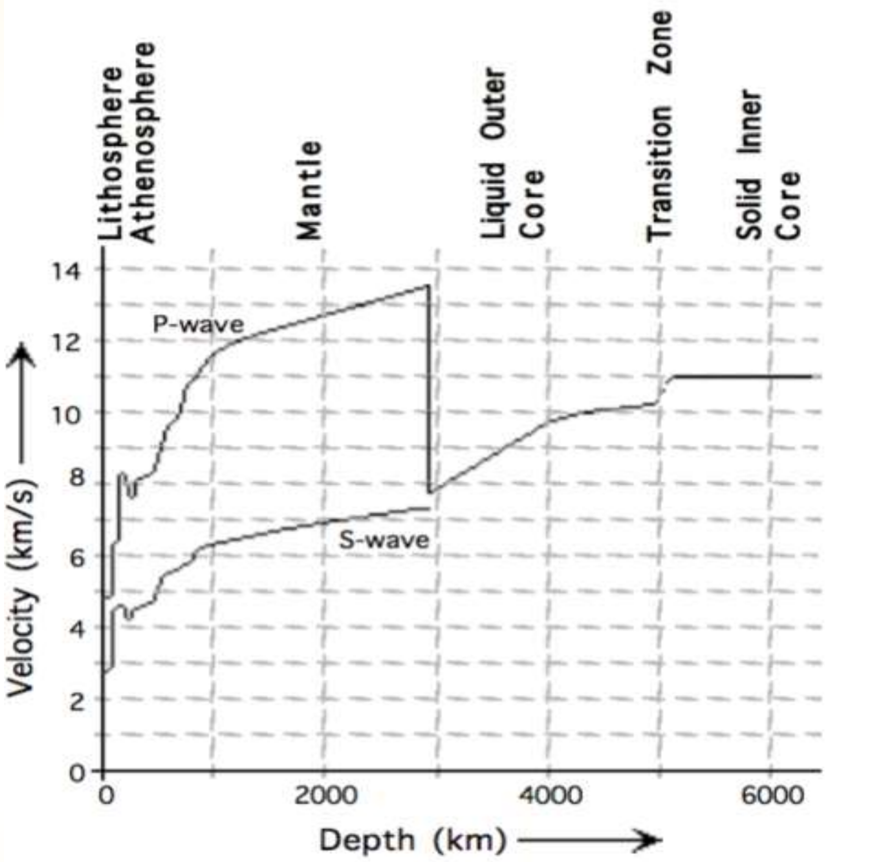
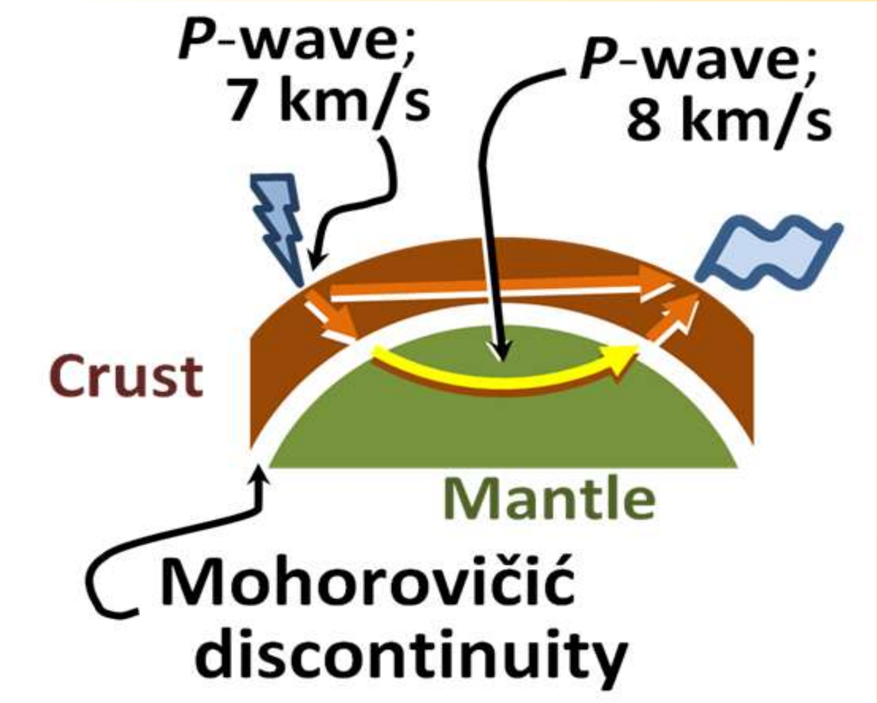


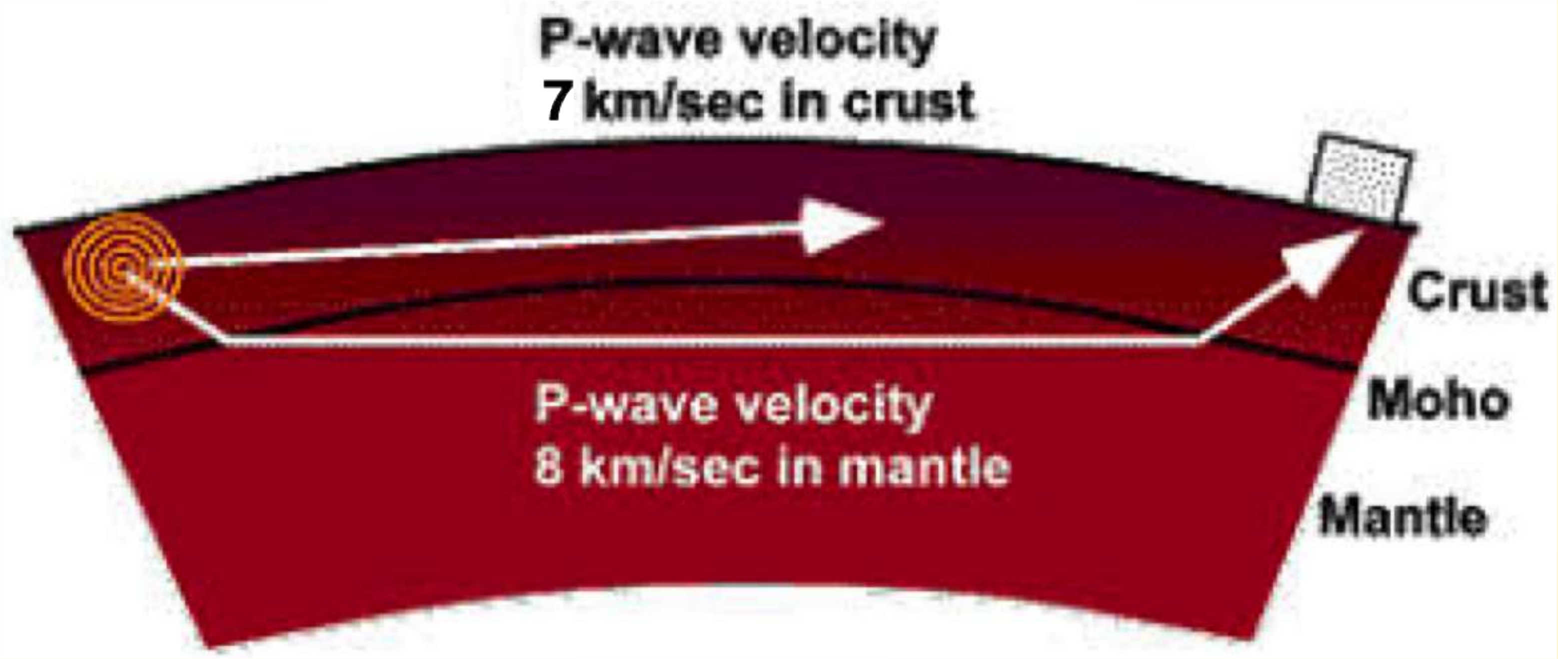
Fig. 22-1 Graph of changes in **P** and **S** wave velocities with depth.

The Moho

- An abrupt change in P- and S-wave **speeds** has been noted at the boundary between the crust and the mantle.
- In 1909, Andrija Mohorovicic found that seismograms often showed two distinct **groups** of P-waves.
- One group travelled at an average speed of 7 km/s while a second group of waves traveled at 8 km/s.

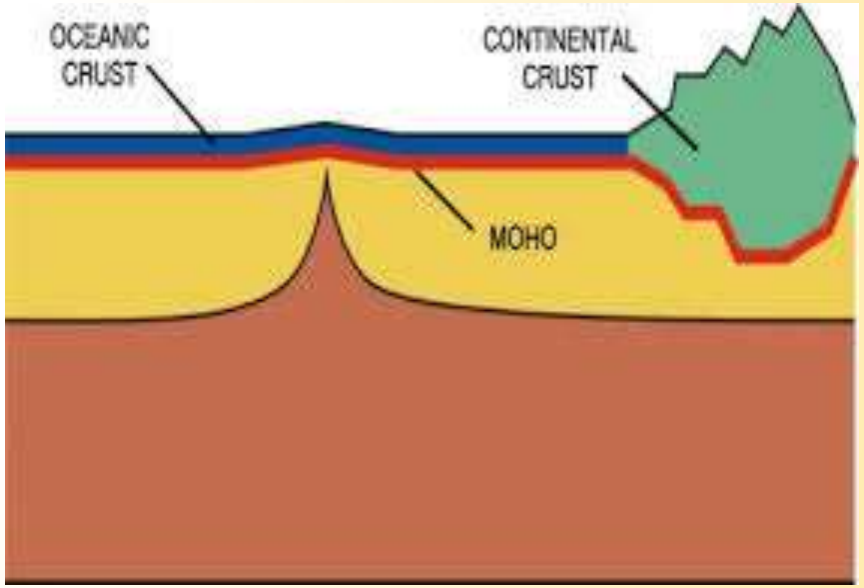


- Mohorovicic reasoned that the faster wave group had passed through denser material below the **crust**.
- This boundary between less and more dense material is known as the Mohorovicic Discontinuity (or 'The **Moho**') and marks the boundary between the crust and the mantle.

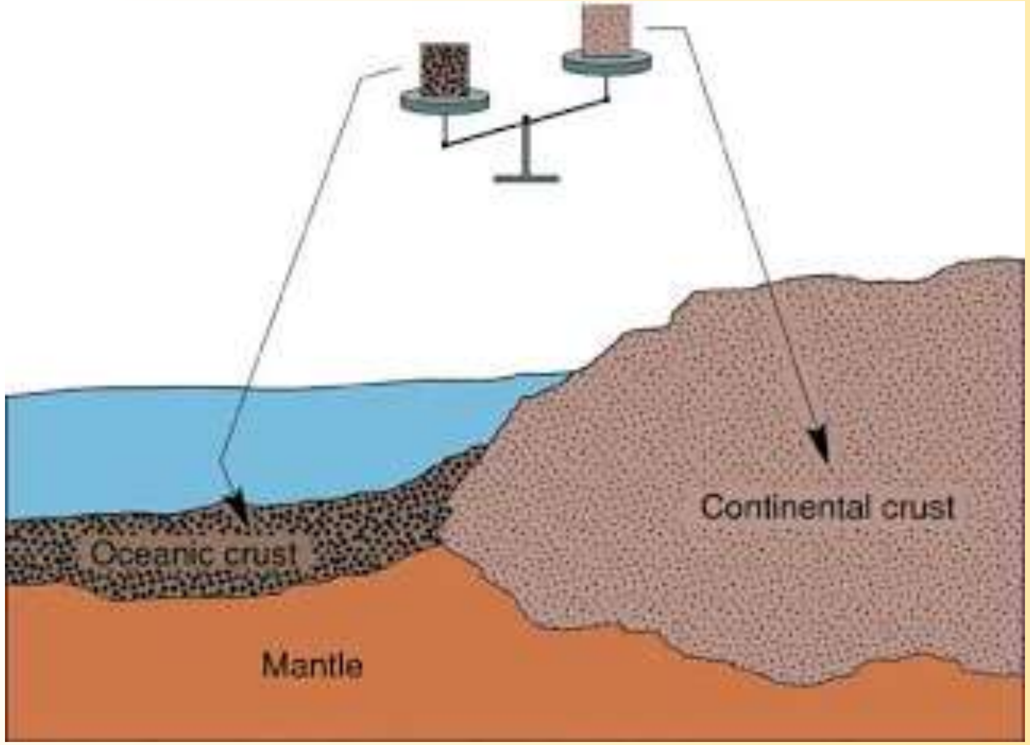


- Mapping of the Moho shows that crustal **thickness** varies.

  - Oceanic crust has an average thickness of about 8-10 km
  - Continental crust has a depth of approximately 40 km, although it can be significantly **thicker** under major mountain ranges.

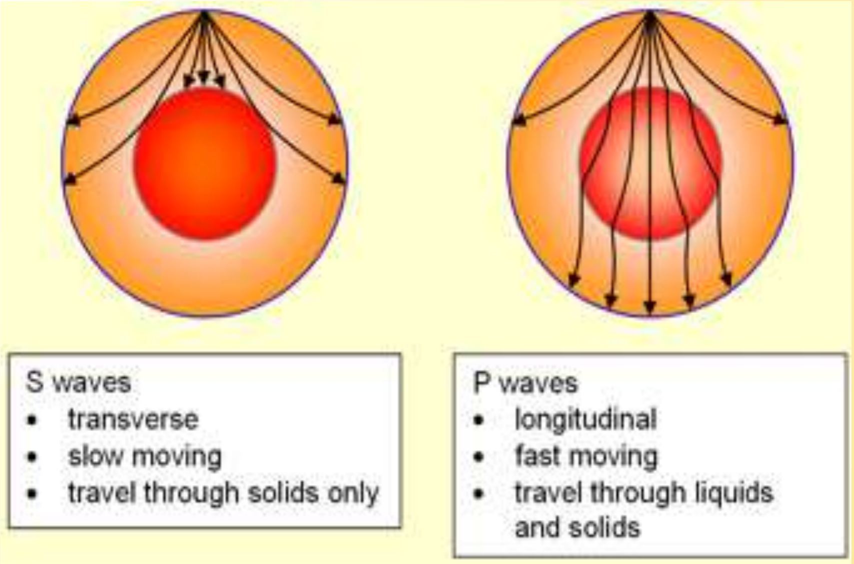


- Slight variations in seismic wave velocities also show that crustal composition **varies**.
  - Oceanic crust is made of relatively dense **basalt**.
  - The thicker continental crust is principally made of less dense **granite** with a variable surface covering of sedimentary and metamorphic rocks.



The Shadow Zone

- Even though an earthquake sends **waves** throughout the Earth's interior, not all seismograph stations receive information.
- At a surface distance greater than 11 000 km from the epicenter, **S-waves** do not arrive.
- Between 11 000 km and 15 000 km, the P-waves also arrive much **later** than predicted.
- Seismic stations that don't receive P or S-waves are said to be in the **shadow** zone.



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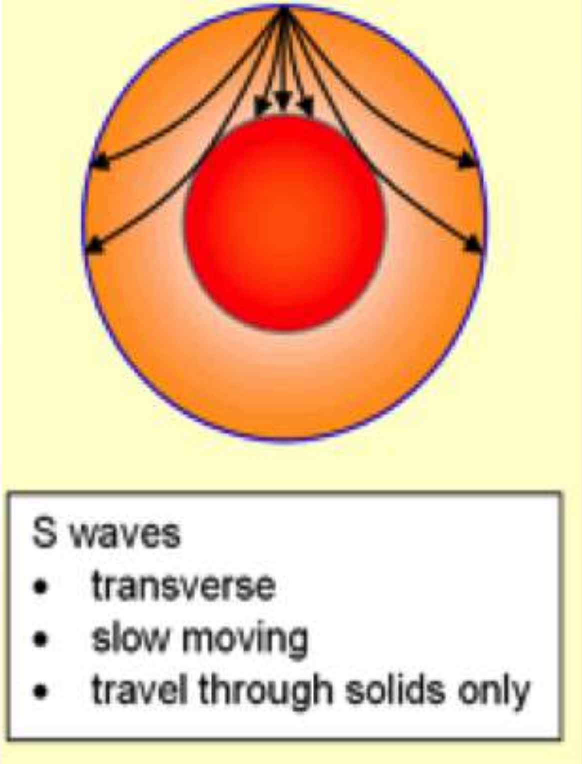
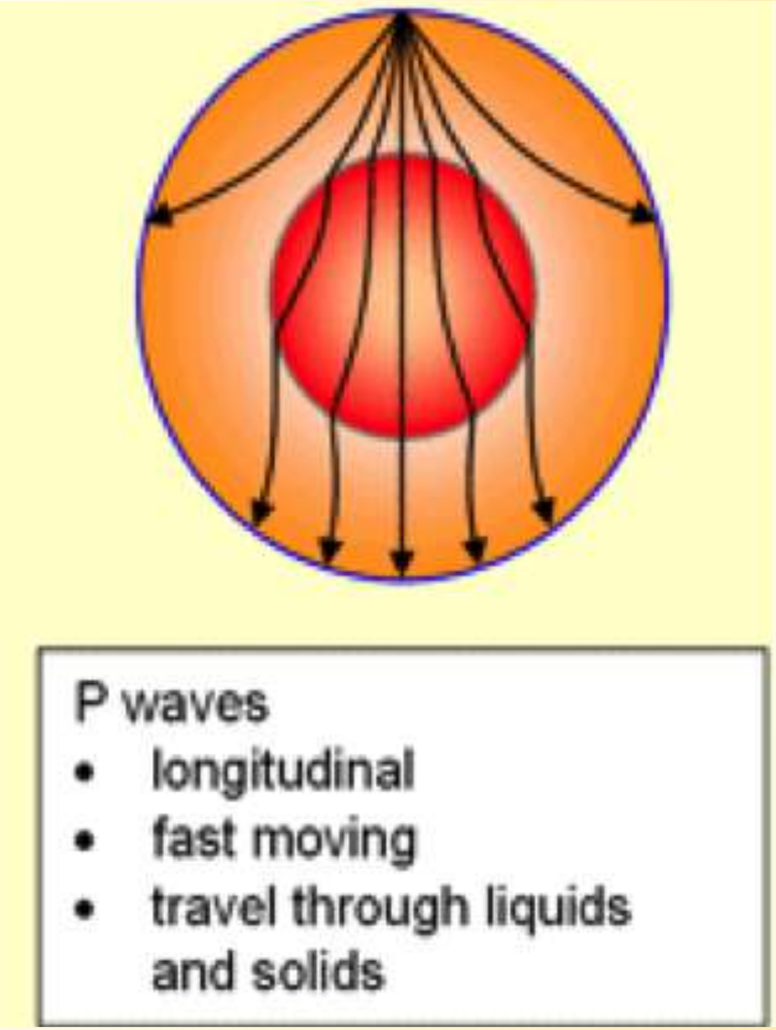
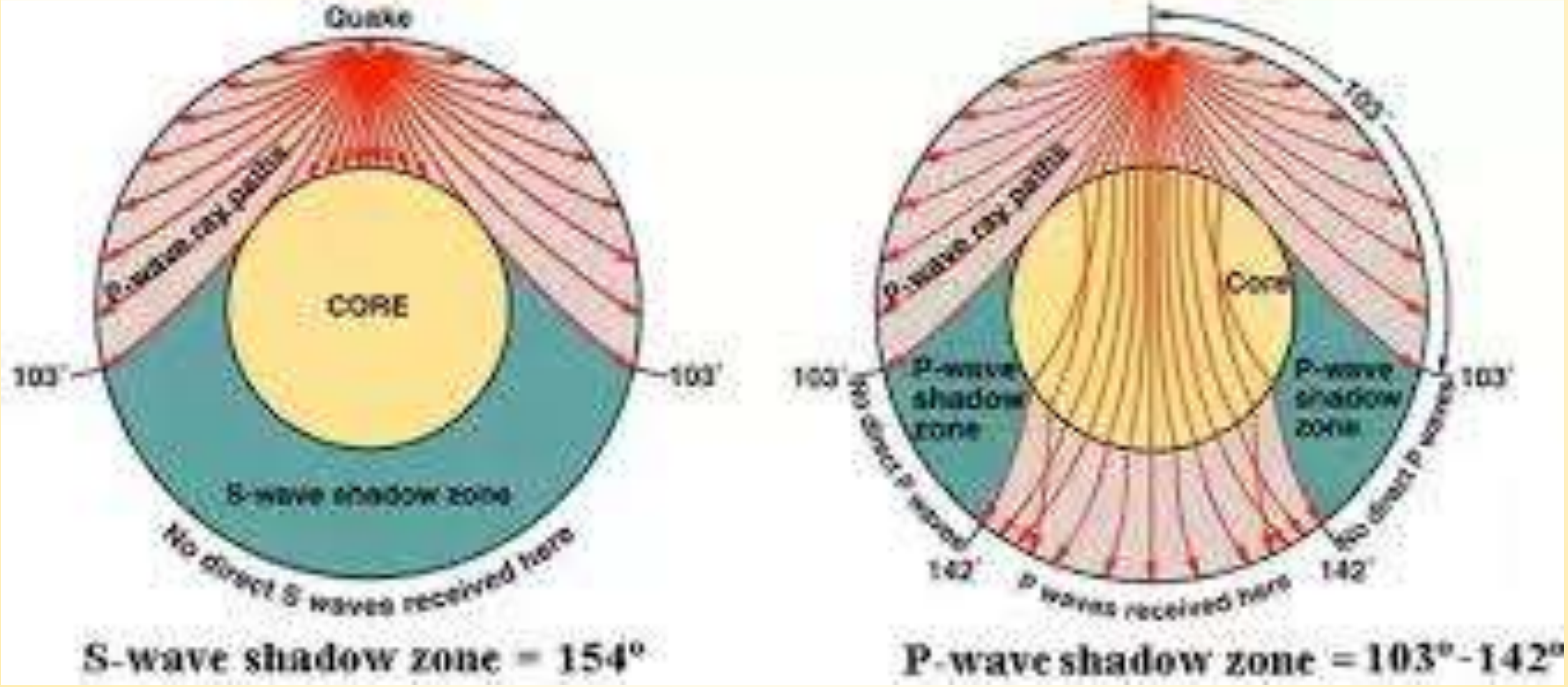


- Between 11 000 km and 15 000 km, the P-waves also arrive much **later** than predicted.
- Distance vs. velocity data show that the S-waves actually **stop** and P-waves slow down and refract at about the 2950 km depth.

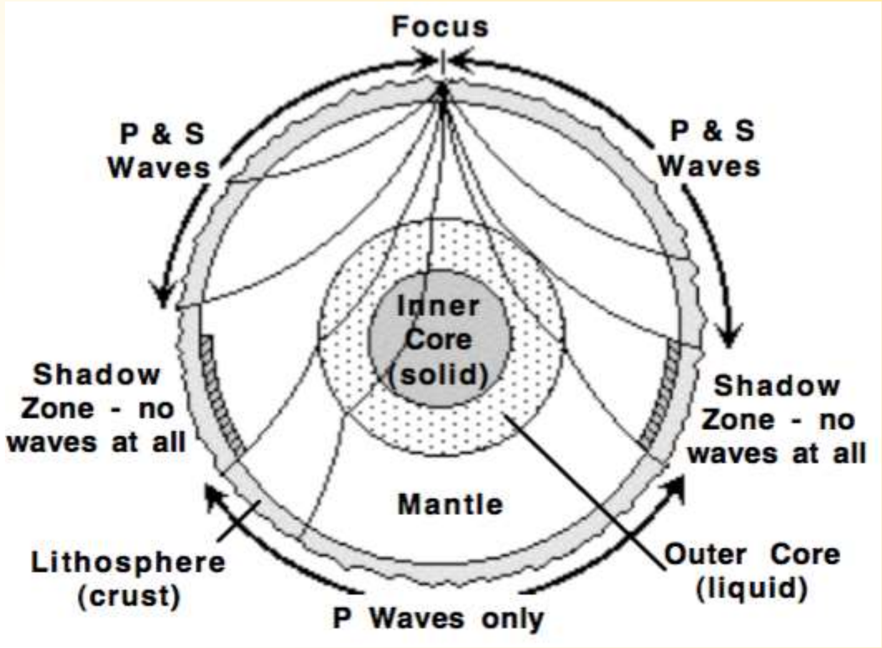


SHADOW ZONE



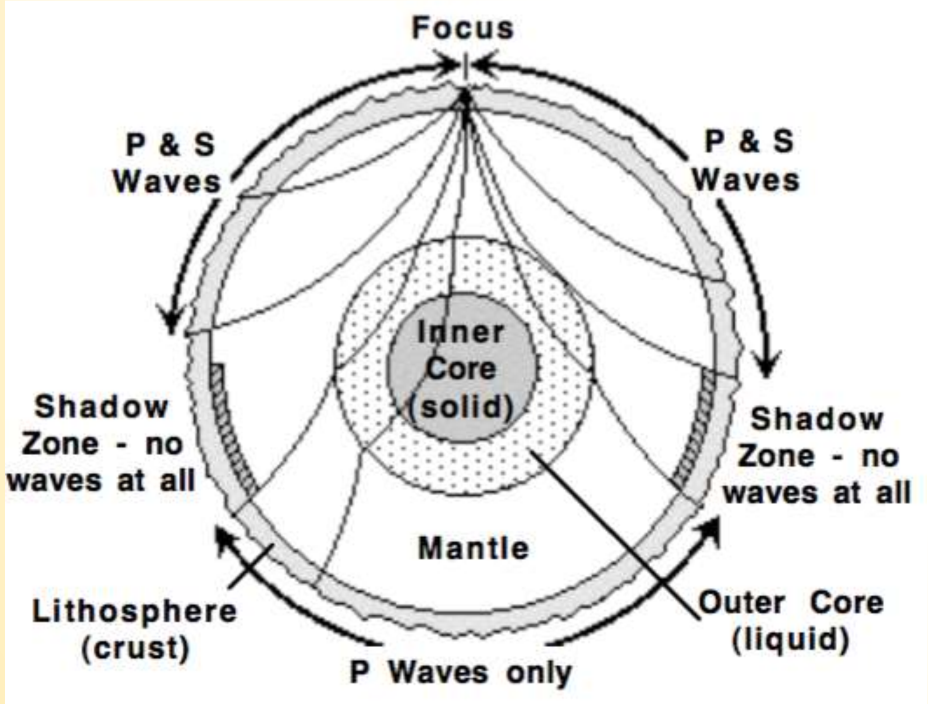
Quake
P-wave ray paths
CORE
103°
103°
S-wave shadow zone
No direct S waves received here
S-wave shadow zone = 154°
103°
P-wave ray paths
Core
P-wave shadow zone
P-wave shadow zone
103°
103°
No direct P waves
No direct P waves
142°
142°
P waves received here
P-wave shadow zone = 103°-142°

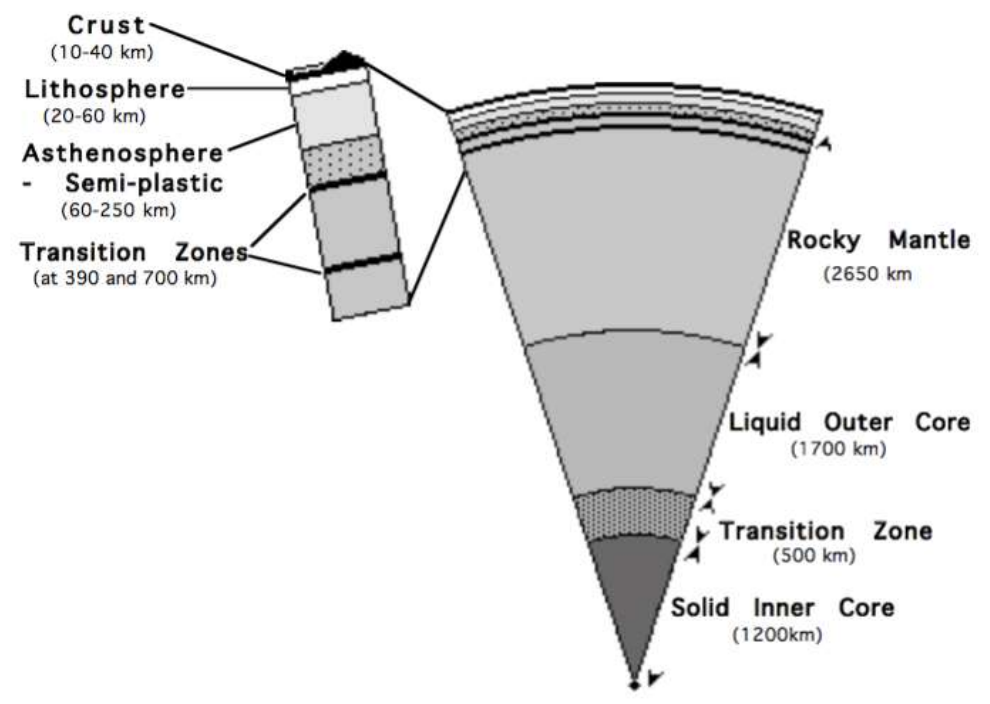
- For the waves to behave in this manner, scientists have theorized that there has to be a **liquid** component to the core (remember that **S** waves do not travel through liquids).



- This would also cause refraction of the **P** waves (explaining their **longer** travel times).

The basic model of the major layers of the Earth's interior, together with the primary pathways of the different types of waves is shown below





7.5 Earthquake Hazards

- The risk of being in an earthquake is very dependent on your **location** on the Earth.
- In Canada the most susceptible areas are the **west** coast of British Columbia and the St. Lawrence Valley.
- The potential for major earthquakes is very high along the coast.
- The last significant earthquake to hit south-western BC was a magnitude 7.3 in the Comox Valley in 1946, an area with considerably less **population** at that time compared with today.

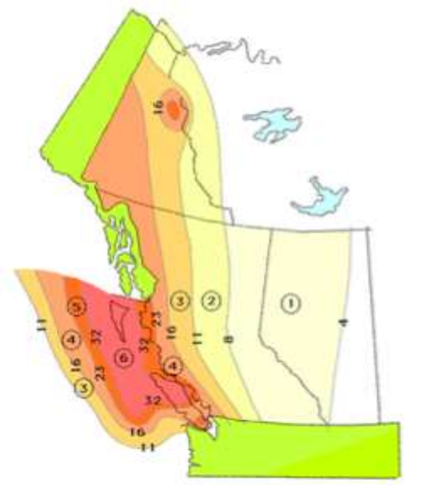


Fig. 21-11 Seismic zoning map for BC and the Yukon. Plain numbers represent horizontal ground velocity in cm/s. Circled numbers (0-6) represent the seismic zone rating.

Ground Shaking

- In movies, it is common to have earthquake scenes where most of the buildings are reduced to heaps of rubble.
- The main cause of such damage is the poor response of the building to **ground shaking**.
- This may be due to either:
    - **poor building design**
    - being built on **unstable** **ground**.

Building Design

- Steel and wood frame buildings are remarkably safe, as they have the ability to **flex** moderately, absorbing much of the seismic wave motion.
- Brittle buildings such as those made of brick, concrete block, unreinforced concrete or adobe cannot flex and are therefore very prone to **cracking** and collapse.
- This is one reason why so many people die in places like the Middle East and Mexico, as their adobe buildings just collapse on top of them during earthquakes.

- Buildings such as showrooms with large **glass** walls and long heavy roof beams are also particularly at risk.
- They are prone to having the **walls** shift enough with the shaking that these heavy beams come away from their support and collapse into the building.
- Tall skinny buildings tend to **sway** because of their height and are therefore at increased risk of cracking.

Ground Conditions

- Building directly onto **bedrock** is the safest as it has the least shaking for a given magnitude.
- However, that is not always possible as can be seen in the Fraser Valley, B.C., where many buildings are constructed on **deltaic** or flood plain deposits, or on **landfill**.
- There is a tendency for the various municipalities in Metro Vancouver to add **fill** to flood plain land that is being developed for housing. .
- Although fill raises the elevation of the house above traditional **flood** levels, the addition of the loose fill will also **magnify** ground motion in a significant earthquake.

Liquifaction

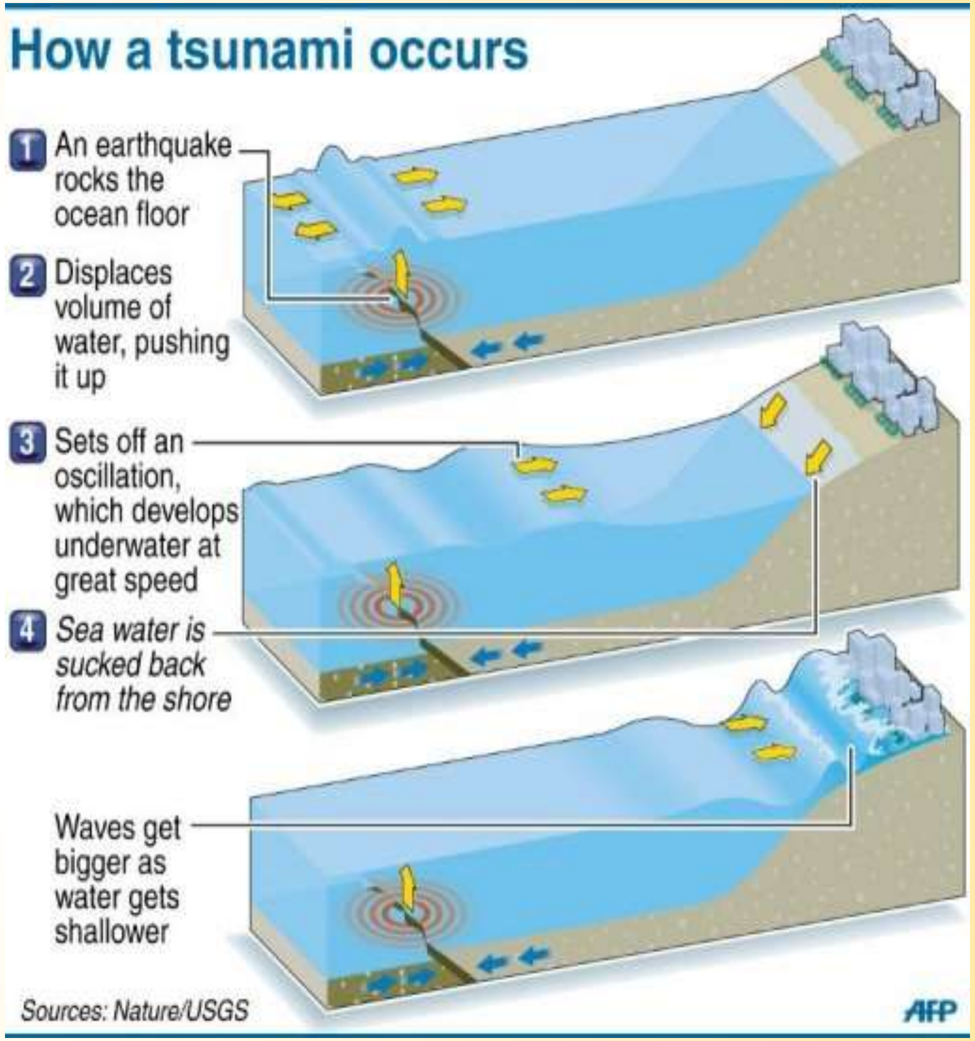
- Liquefaction occurs when loose sediments and have a high **water** content.
- The shaking of the ground causes the material to settle at a lower level.
- Buildings tend to **sink** or tilt over, built up roadways and railways tend to slide apart and bridges buckle.

https://www.youtube.com/watch?v=4Uwxr42JqYQ

Tsunamis

- If an earthquake occurs offshore, movement of the sea floor or underwater landslides can result in **tsunamis**.
- When a column of water is displaced, a disturbance is sent out and large sea waves can occur.

- Out in the depths of the ocean, tsunami waves are not apparent
- As the **depth** of the ocean decreases, the waves build higher and higher.
- Tsunami waves often look like **walls** of water by the time they reach the shoreline, with subsequent waves striking every 5 to 60 minutes for hours.



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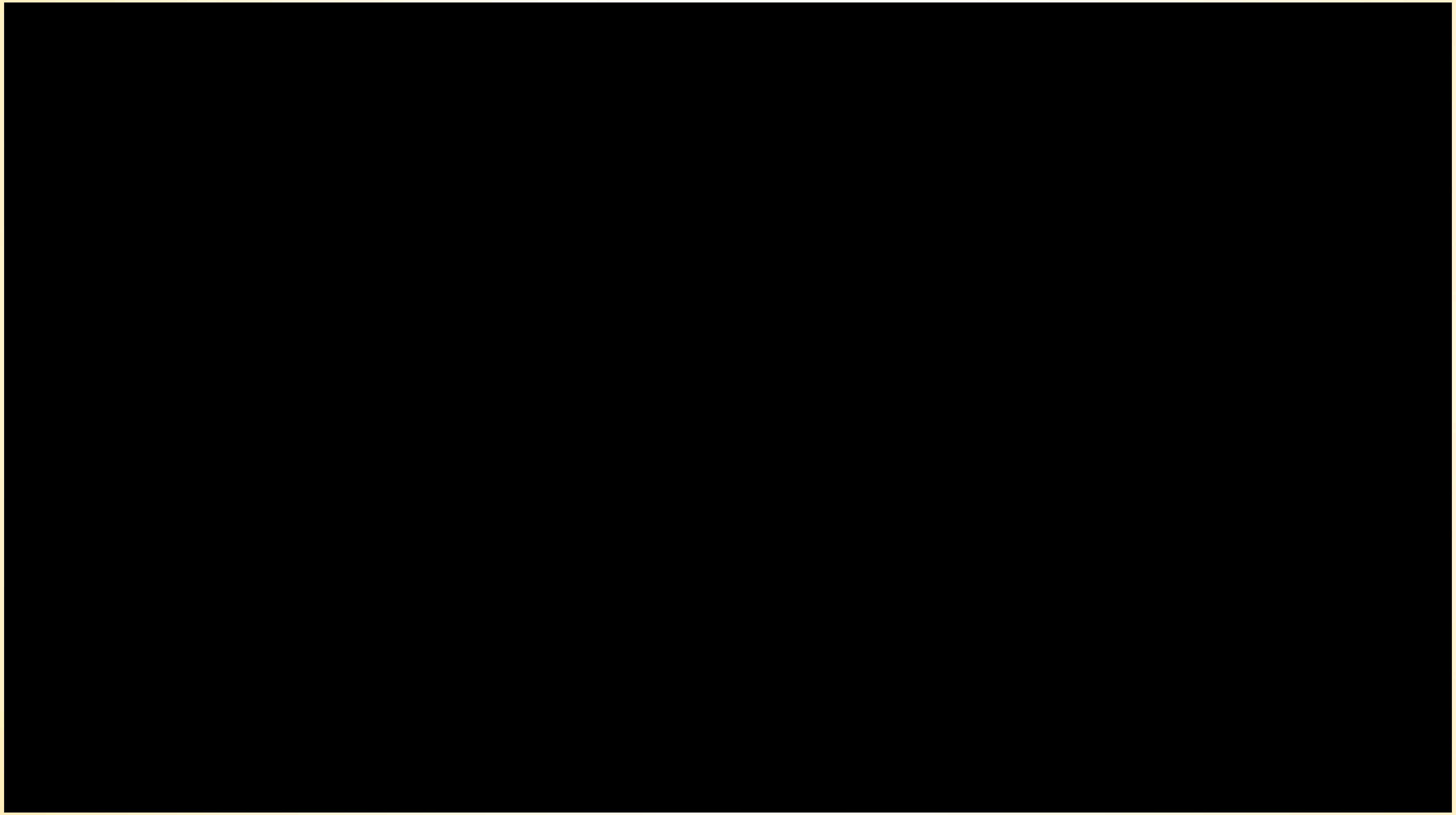

7.6 Earthquake Safety

- If you live and work in **high**-risk areas such as South West B.C. there are a number of basic preparations and precautions that you can take to reduce the likelihood of damage and help you **survive** the first few days.

- Screw all heavy tall furniture into the **wall**.
  - Do not place heavy objects on top of such structures.
  - Do not hang a picture or mirror above your **bed**.

- Keep an adequate First Aid and **Emergency** kit available and know how to use it.
- Include water purification tablets in case you have to resort to drinking **unsafe** water - most natural creeks in the Fraser Valley carry the Giardia (beaver fever) parasite, for example.
- Flashlights and a portable radio are necessary, but make sure that the **batteries** are checked regularly.

- Keep three or four 4 L milk jugs (or similar containers) of fresh drinking water in a safe place and replace monthly
- Have a stock of basic **foods** also in a safe place – like water, rotate and replace the food on a regular basis.
- A portable stove, a tent and sleeping bag are useful in case you have to camp **outside** for a day or two before you can get to an emergency shelter.
- Keep all of your "kit" in an **accessible** place!
- Regularly practice basic safety routines, as a family and at work, so that if there is an earthquake your response will be **automatic**.

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What should you do when the ground starts to shake?

- Keep calm. DO NOT panic and run **outside**.
- Many injuries and deaths from earthquakes occur because frightened people run out into the street just as chimneys and other such objects are falling.

If you are INDOORS:

- Take **cover** immediately under a sturdy table or desk, or any object that will protect you against falling fixtures and ceilings.
- If no cover is available, stand under a **doorway** or against an inside wall.
- Face away from the windows so that if they do break any flying **glass** will hit the less vulnerable parts of your body,
- **The first waves that you feel are not usually the most damaging and so you have some time to take cover before the later more damaging waves strike.**

- Count out aloud to **60** seconds before you come out from your cover, assuming you are not trapped.
- The sound of your own and other voices exert a **calming** effect.
- DO NOT go back into a damaged **building**, unless it is absolutely necessary to rescue an injured person.

If you are OUTSIDE:

- If you in open flattish country, you are probably in the **safest** place in which to experience a strong earthquake.
- In areas of unconsolidated ground such as loose gravels and shales, the shock waves may uproot or snap the tops off **trees**, or even cause the ground to **slump** and slide.

If you are DRIVING in a car:

- pull into the **center** of the road as far away as possible from surrounding buildings and street fixtures.
- Stay in your car until the earthquake stops as it offers you more protection from **falling** objects than being outside.

- If you are close to the Pacific coast there is the possible risk of a **tsunami**.. If there is a tsunami warning, evacuate **low-lying** areas.
- Do not clog up the **roads** which may have also been damaged, making it difficult for rescuers to travel.
- Tune in a portable radio and wait for further instructions.

- Stay away from downed **power** lines until you know for certain that they are dead .

- It would be rather ironic to survive a 7.9 earthquake only to step outside and be fried on a downed 500 kV power line!