Earthquakes and Faults

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1 Introduction

Earthquakes are some of Earth's deadliest natural disasters. They destroy homes and property, take the lives of thousands each year, and yet are a key component in understanding how Earth's crust functions. The largest earthquakes are caused by faults in the lithosphere that can span continents and crush rock. These faults, and the effects they cause, will be detailed in the following handout.

2 Types of stress

Faults are brittle fractures in rock. These fractures are formed from different types of force, or stress, exerted on the ground. Forces can be categorized into **pushing** (compressional), **pulling** (extensional), or **sliding** (shearing) stresses. Let's take a deeper look at each type of stress.

2.1 Compressional

When you push a ball of clay together between your hands, the clay bulges and extends. This is an example of **compressional** stress. When the ground is pushed into itself, it thickens and folds underneath the pressure. This thickening is what creates mountains and mountain ranges - just think of Mount Everest! That mountain was created due to compressional stress introduced by the Indian subcontinent colliding with Asia; these kinds of continental interactions will be detailed later in this handout.

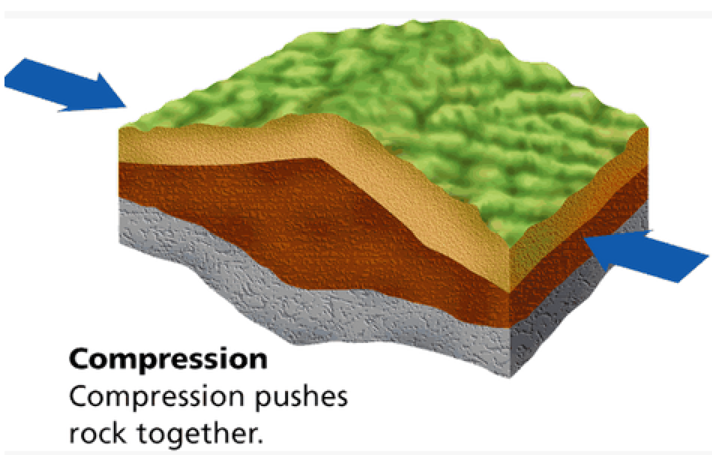


Figure 1: Compressional stress visualized (Credit: mhshonorsenvr.weebly.com)

2.2 Extensional/Tensional

When you pull a ball of clay apart, the clay tears and breaks. This is an example of **extensional** stress. When the ground is pulled apart, it thins and fractures under the force of gravity. This causes something called normal faults to form - a kind of breakage in the rock that slides down under its own weight.

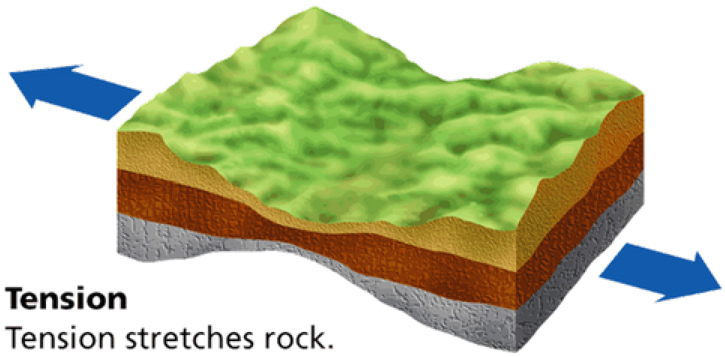


Figure 2: Tensional stress visualized (Credit: mhshonorsenvr.weebly.com)

2.3 Shearing

When you take a ball of clay and smear it in different directions, the clay bends and deforms. This is an example of **shearing** stress. When the ground slides against itself, it rubs and grinds along the fault's surface. This causes objects on different sides of the fault to move further and further away from each other horizontally. It can even create 90 degree bends in rivers!.

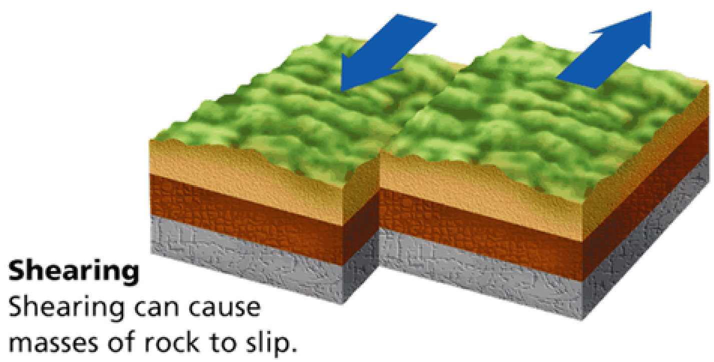


Figure 3: Shearing stress visualized (Credit: mhshonorsenvr.weebly.com)

3 Faults and their behavior

3.1 Hanging walls and footwalls

When rock is compressed or extended, it tends to form diagonal cracks. The face of the crack itself is called the fault plane. The section, or block, of rock that is above the fault plane is called the "hanging wall," while the block below the fault plane is the "footwall."

REMEMBER! This classification doesn't change, no matter what type of fault. A block that is moving upwards but is above the fault plane is just as much a hanging wall as one moving downwards above the plane.

Scarps are the exposed surface left above ground by fault movement. They can be angled inwards or outwards, depending on which fault caused them.

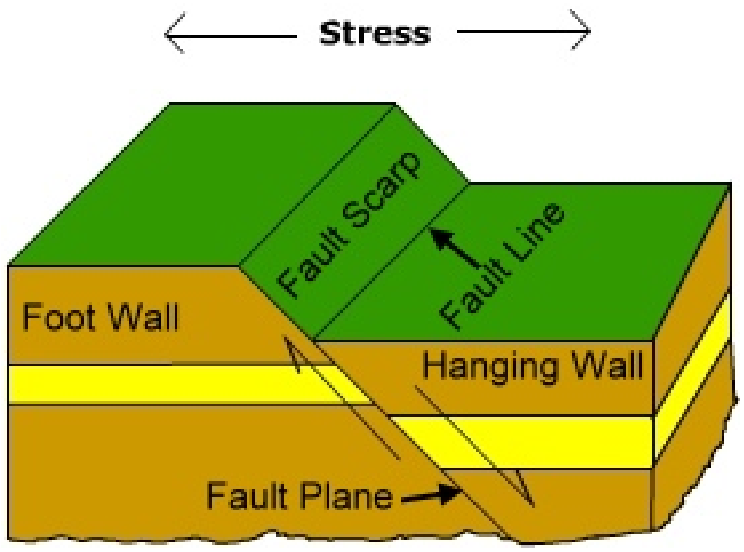


Figure 4: Obtuse angled scarp (Credit: https://golearngeo.files.wordpress.com/2010/02/normal_fault_labelled_diagram.jpg)

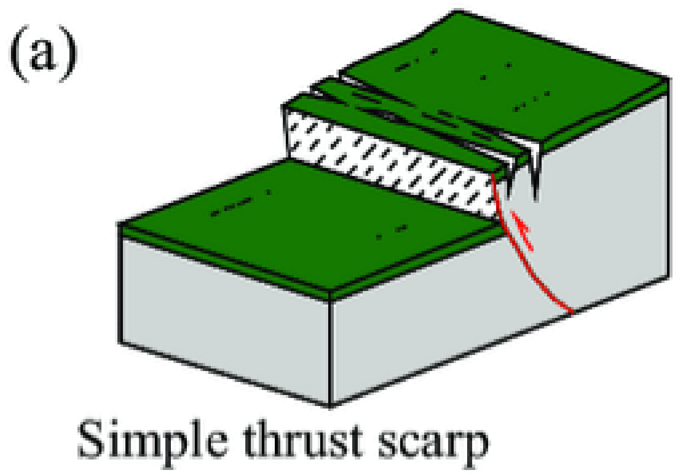


Figure 5: Acute angled scarp (Credit: https://www.researchgate.net/figure/Scarp-type-classification-modified-after-Philip-et-al-1992-and-Yu-et-al-2010-The_fig1_322601907)

3.2 Types of faults

As seen above, many different types of stress can be exerted onto rock in nature. Each form of stress causes a unique type of fault, determined by the forces present in the area. To categorize a fault, look at its **hanging wall**, its **footwall**, and their relative motion.

3.2.1 Normal faults

Normal faults are characterized by the dominance of gravity. They occur when the hanging wall moves downwards in relation to its footwall.

Normal faults occur in areas of extensional stress. It makes sense - when you take away pressure from an object, like taking a large book from a full bookcase, it moves downwards and outwards.

Figure 6: Books sliding down (Credit: https://fr.depositphotos.com/stock-photos/dogeared.html)

You can remember what normal faults are by thinking of the way the hanging wall moves. When you put something with a concave slope on one with a convex slope, the concave block is the one that normally moves downwards, due to gravity.

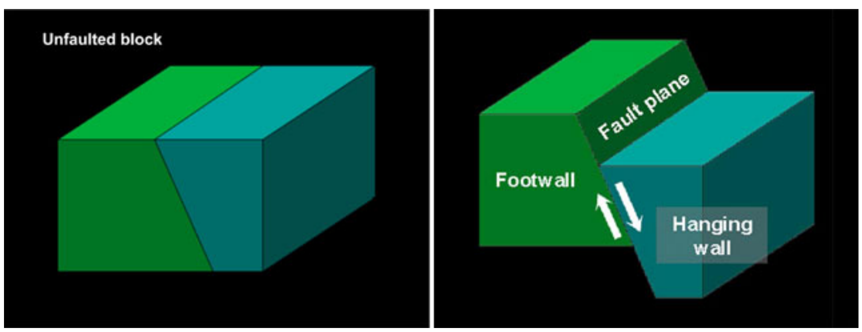


Figure 7: Normal fault illustration (Credit: https://sites.radford.edu/ jtso/GeologyofVirginia/Structures/GeologyOfVAStructures4-2b.html)

Geographical features Fault block mountains are special geographical features, where areas of relatively high elevation have not been created through uplift but through faulting and subsidence of the surrounding land.

This shape is called *horst and graben topography*. Horsts and grabens represent areas of uplift and subsidence, respectively.

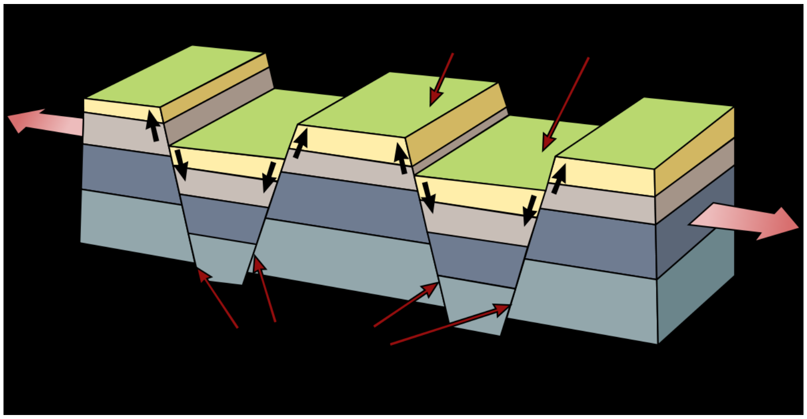


Figure 8: Horst and graben illustration (Credit: https://en.wikipedia.org/wiki/Graben/media/File:Fault-Horst-Graben.svg)

The Basin and Range province of the U.S. is an example of horst and graben topography. It was created by tectonic extensional stress on the North American plate about 17 million years ago. An alternating and abrupt change in height, due to normal faults, is a hallmark of horst and graben structures.

Figure 9: Aerial shot of the Basin and Range province (Credit: https://en.wikipedia.org/wiki/Basin$_and_Range_Province/media/File:$ $Basin-range-province.jpg$)

Normal faults are also associated with expansion and slumping, and so are common in sedimentary basins. Their nature means they also tend to trap petroleum and hydrocarbons, making them economically valuable.

3.2.2 Reverse faults

Reverse faults are characterized by the dominance of compression. They occur when the hanging wall moves upwards in relation to its footwall.

Reverse faults occur in areas of compressional stress. Think about when you push a block up a slope - you're forcing the block into the slope, which then forces it upwards.

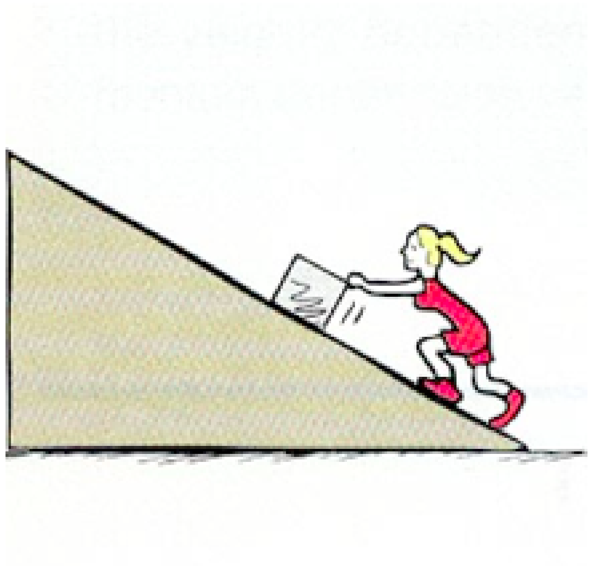


Figure 10: Pushing a block up a slope (Credit: https://www.pathwayz.org/Tree/Plain/WORK)

You can remember the way reverse faults move because they go in the opposite, or reverse, direction of gravity. Where you might expect the hanging wall to slip down, it instead pushes upwards.

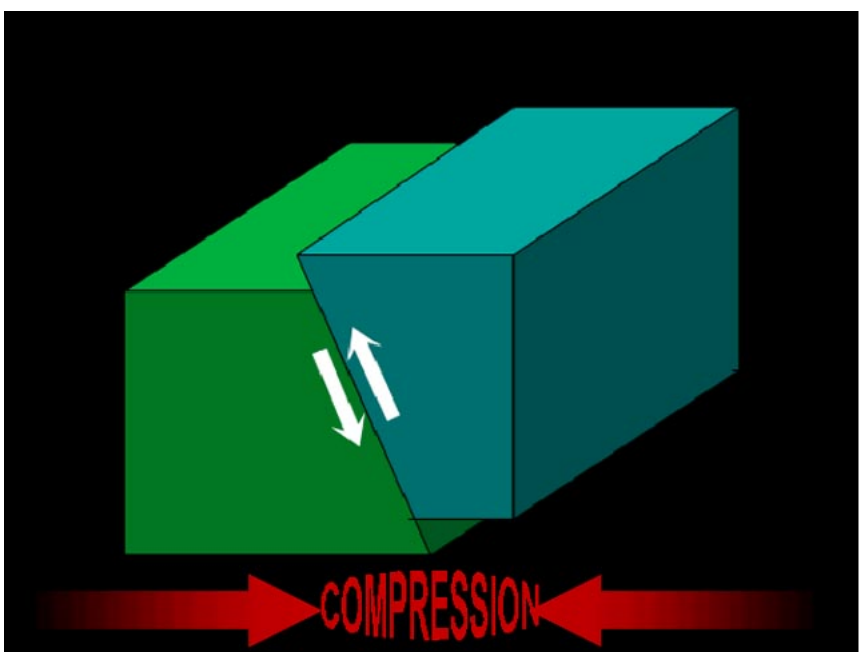


Figure 11: Reverse fault visualization (Credit: https://sites.radford.edu/ jtso/GeologyofVirginia/Structures/GeologyOfVAStructures4-2c.htmlReverse)

Thrust faults Thrust faults are special types of reverse faults, classified by the angle they make with the ground. If the angle is *less than 15 degrees*, the reverse fault is said to be a thrust fault.

Thrust faults are results of significant compressional stress, such as when two continental plates collide and neither can subduct, forcing both slabs of rock upwards.

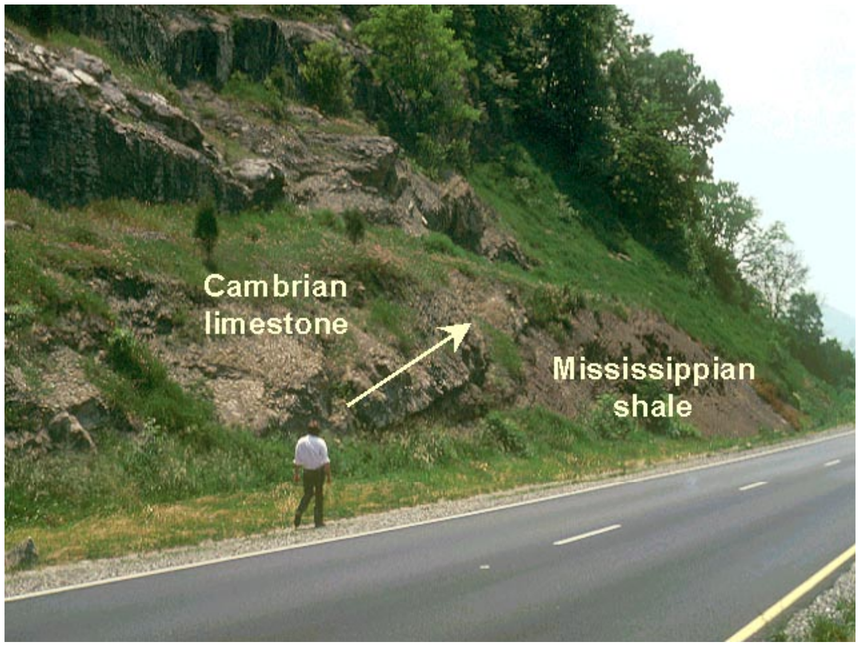


Figure 12: Cambrian rock thrust over Mississipian in Scott County (Credit: https://sites.radford.edu/ jtso/GeologyofVirginia/Structures/GeologyOfVAStructures4-2c.html)

The largest thrust faults are convergent boundaries, where two plates collide and interact. That's where the largest earthquakes happen, as well as the most metamorphism - for those familiar with the metamorphic facies chart, the subduction gradient refers to this kind of fault!

3.2.3 Strike-slip faults

Strike-slip faults are characterized by the dominance of shearing. They don't have a hanging or a foot wall; instead, there are two blocks that move parallel to each other.

Strike-slip faults occur in areas of shear stress. Think about when you slide two wooden blocks in opposite directions, and the way objects that might once have been aligned grow further and further apart.

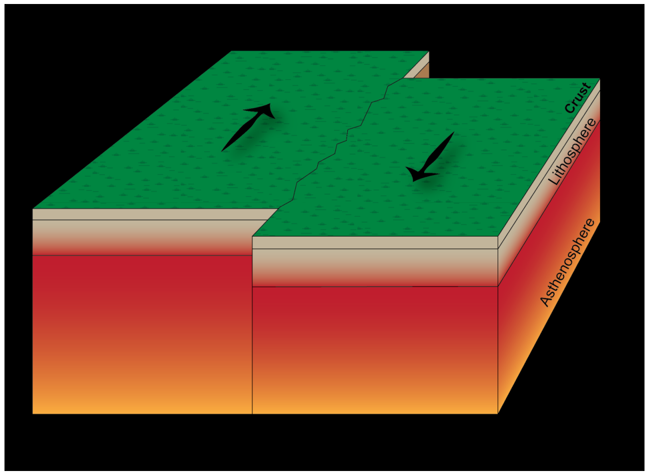


Figure 13: Strike-slip fault visualized (Credit: http://ds.iris.edu/aed2/c/alaska/popups/tectonics/tec$_{1t}ransform.html$)

The San Andreas fault in California is one of the largest and most well-known strike-slip faults in the U.S.A. In the image below, see how the path of the river has been transformed horizontally by the movement of the fault.

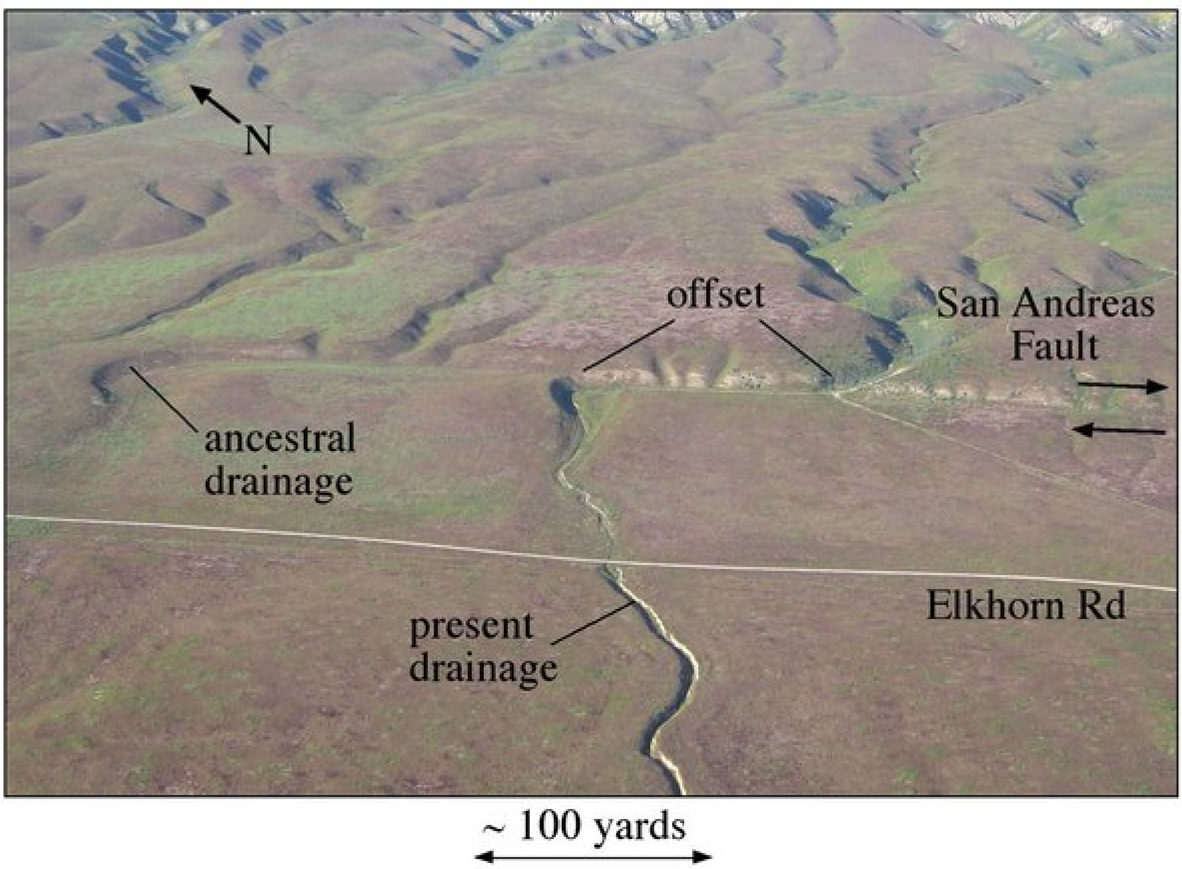


Figure 14: A river crossing the San Andreas fault (Credit: https://epod.usra.edu/blog/2006/12/aerial-photo-of-wallace-creek-and-san-andreas-fault.html)

3.3 Types of deformation

When stress is applied to rock at the surface, we all know what happens - the rock fractures, shifts, and eventually breaks. But under high enough pressures or temperatures, rock can actually bend and fold like cloth!

At the surface, rocks exhibit **brittle deformation**, the kind everyone is familiar with - think of glass or stone shattering. But at depth, rocks can exhibit **ductile deformation**, where they warp instead of break. The depth at which this begins to happen is called the *brittle-ductile transition*.

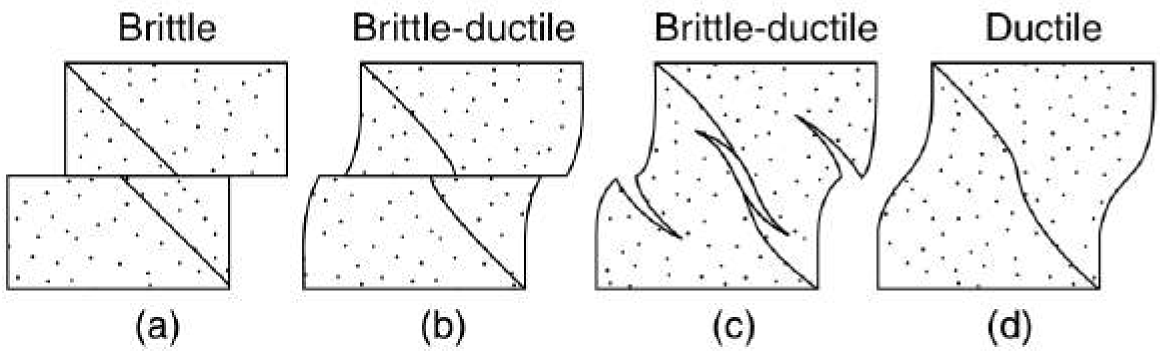


FIGURE 5.21 Brittle (a) to brittle-ductile (b, c) to ductile (d) deformation, reflecting the general subdivision between faults and folds that is used in the subsequent parts of the text.

Figure 15: Varying levels of brittle and ductile deformation (Credit: https://www.eri.u-tokyo.ac.jp/people/ichihara/vp2007plan/15ShearZones.html)

3.3.1 Boudinage

Different rocks behave differently under varying pressures, temperatures, and stressors. In some cases, a ductile and nonresistant rock layer may surround a brittle and resistant one. When these layers are stretched, the brittle layer starts to break up while the ductile layer fills in the fractures. This forms sausage-shaped formations called boudins. The exhibition of this formation is called **boudinage**.

Figure 16: Rock exhibiting boudinage (Credit: https://blogs.egu.eu/divisions/ts/2019/05/19/features-from-the-field-boudinage/)

3.4 Strike and dip of faults

Strike and **dip** are the two things needed to define a fault plane. Strike is the line the fault plane makes when contacting the surface, while dip is the angle the fault plane makes with the surface. Using strike and dip notation allows you to transform a 2D line into a 3D fault with minimal information.

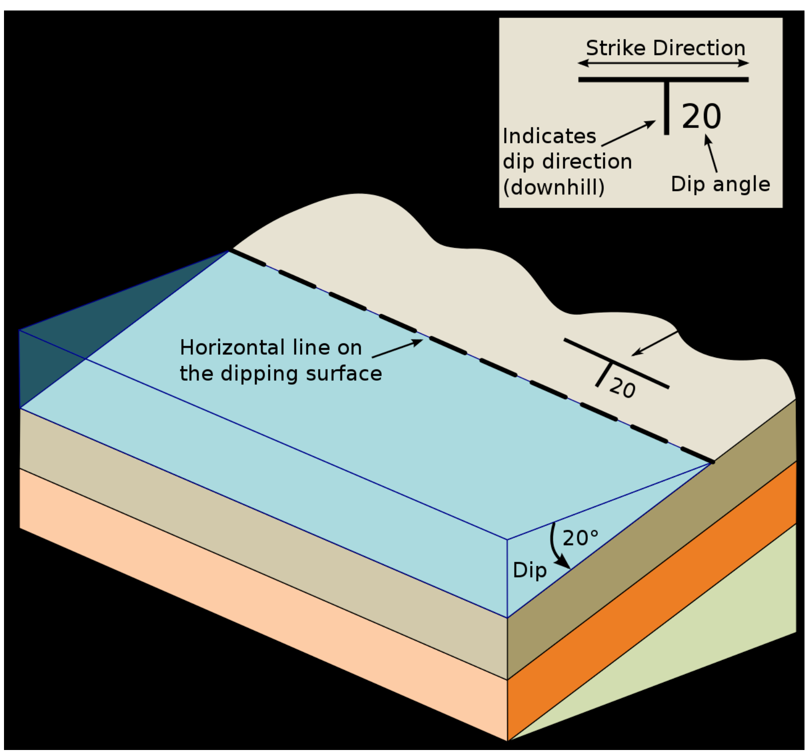


Figure 17: Strike and dip visualization (Credit: hhttps://en.wikipedia.org/wiki/Strike$_{a}nd_{d}ip/media/File : Strike_{a}nd_{d}ip_{o}n_{b}edding.svg$)

The concepts behind strike and dip can be applied to calculate various trigonometry-related questions, such as the depth of the fault plane at a certain distance away from the intersection of the plane and the surface.

You can use the relationships between the sides of a right triangle to calculate any number of qualities about a fault, as long as you have the direction the fault travels in and the angle with which it dips into the ground.

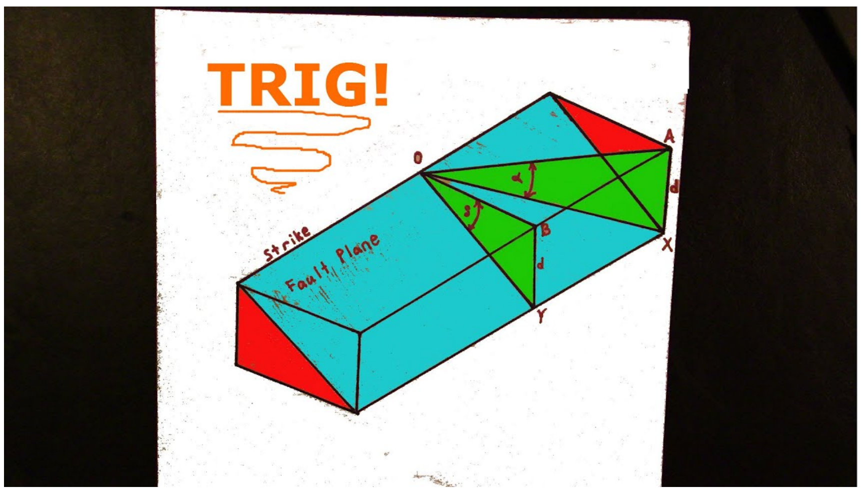


Figure 18: Illustration of geometry present in a fault plane (Credit: https://www.youtube.com/watch?v=lpmdriLFmkc)

4 Earthquakes

In 2015, earthquakes alone directly or indirectly caused the deaths of about 9,624 people. What is it that makes these events so deadly, and what causes them in the first place? Read on to find out.

4.1 What causes earthquakes?

In the previous section, we learned about faults and how they moved. But in the real world, a fault is not two perfectly smooth blocks sliding across each other. Rock is rough and heavy - in a lot of cases, the movement of a fault is very choppy, as the dominant force in that specific fault must build enough tension to overcome the force of friction. And there is a lot of friction between two rock faces; think of all the rocks you've ever touched. They're bumpy and jagged and textured - all of these little imperfections get caught on each other, meaning that shifting the blocks of a fault, even a little, requires a lot of energy. And when that much pent up energy is released, when the rock faces slip past each other, an earthquake can happen.

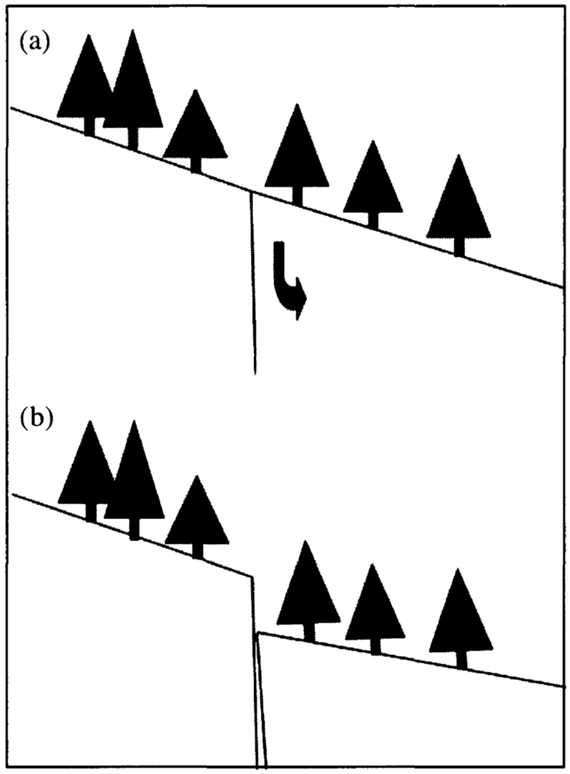


Figure 19: Before and after fault slippage (Credit: https://www.researchgate.net/figure/Diagram-illustrating-movement-of-land-blocks-adjacent-to-the-Hebgen-fault-before-a-and$_fig2_2$48906802)

In short, faults don't slip smoothly over each other. They get caught, and when they build up enough energy to slide past each other, the energy can be released as an earthquake. After slipping, the fault blocks get caught on each other again, and the process starts all over.

All earthquakes are caused by faults, *but not all faults create earthquakes!* Some are too small, or their movement too smooth, to store up enough potential energy.

4.2 Epicenter and hypocenter

When a slippage in a fault plane happens, it's often not the surface that fails first. Usually, there is a point underground where the stress finally beats out the friction - from there, there's a cascading effect across the fault plane until an entire chunk of rock loosens enough to move.

This point of first failure is called the **hypocenter**, or focus. It's where the energy of an earthquake actually originates - hypo, a Greek prefix meaning "under," indicates that it's below the surface. However, maps are not three dimensional, and humans can't sink into the ground either. This is why the epicenter is used. It's the point on the surface directly above the hypocenter and is used as an useful estimate for the center of an earthquake.

4.3 Processing earthquake data

Gathering accurate, useful data about earthquakes is critical as the information can be used to prevent loss of life and property. This means that a variety of instruments are employed all across the world to measure and scale the dozens of earthquakes that happen each day.

4.3.1 Measuring earthquakes

Seismographs Seismographs are the most important instrument used in measuring and recording an earthquake. The system is actually composed of a seismometer, which senses the shaking of the ground, and a timing and recording device, which documents the seismometer's readings.

A simple seismometer is similar to a weight, hanging from a spring, both attached to a frame that moves with the motion of the Earth. This provides a relative sensing of up-and-down movement. While a seismometer can *sense* movement, it can't record it.

A rotating drum and a pen attached to the weight allows a seismometer to document the movements it reads. A rotating drum and a pen are the most often used for a kinemetric seismograph; the resulting pen-drawn graph is called a seismogram.

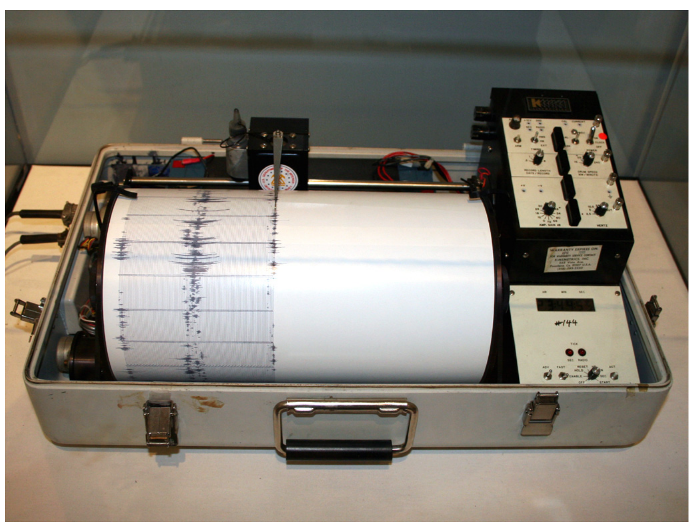


Figure 20: A seismograph recording data (Credit: https://en.wikipedia.org/wiki/Seismometer/media/File:Kinemetrics$_{s}eismograph.jpg$)

A seismoscope is a precursor to the seismometer in that it senses the occurrence, and sometimes direction, of an earthquake, but nothing about the earthquake itself. The first such device was invented in 132 CE by Zhang Heng of China, in the shape of an urn with dragon and frog heads. When the ground shook, balls held loosely in the dragon mouths dropped into the waiting frogs below. The specific balls that fell indicated the direction the quake came from.

Figure 21: An ancient seismoscope design (Credit: https://www.britannica.com/science/seismograph)

Scaling Earthquakes Earthquakes can vary in size, from small quivers to massive rumbles. But how do you quantify the severity of an earthquake? Multiple scales have been devised in order to answer this question. They are detailed further below.

- Moment Magnitude Scale
  - The Moment Magnitude Scale (also MMS, or M_w) defines a quake's size using its seismic moment. The seismic moment measures the movement of rock along the part of the fault that slipped.
  - The seismic moment formula is:

$$M_0 = \mu AD$$

    Where:
    μ = the shear modulus of the rocks (a property that indicates how resistant a rock is to shearing deformation)
    A = the area of rupture along the fault
    D = the average slip on area A
  - The MMS is the most commonly used scale for earthquake magnitude today, as it is better at identifying large quakes that cause more damage.

- Modified Mercalli Scale
  - The Modified Mercalli Scale defines a quake's intensity based on observed effects on the surroundings it passes through. In this way, it converts qualitative to quantitative data.
  - The scale was first created as an offshoot of an earlier intensity scale, the Rossi–Forel scale of 10 degrees, by Giuseppe Mercalli. The first was created in 1883, but failed to gain popularity.

CIIM Intensity	People's Reaction	Furnishings	Built Environment	Natural Environment
I	Not felt			Changes in level and clarity of well water are occasionally associated with great earthquakes at distances beyond which the earthquakes felt by people.
II	Felt by a few.	Delicately suspended objects may swing.		
III	Felt by several; vibration like passing of truck.	Hanging objects may swing appreciably.		
IV	Felt by many; sensation like heavy body striking building.	Dishes rattle.	Walls creak; window rattle.	
V	Felt by nearly all; frightens a few.	Pictures swing out of place; small objects move; a few objects fall from shelves within the community.	A few instances of cracked plaster and cracked windows with the community.	Trees and bushes shaken noticeably.
VI	Frightens many; people move unsteadily.	Many objects fall from shelves.	A few instances of fallen plaster, broken windows, and damaged chimneys within the community.	Some fall of tree limbs and tops, isolated rockfalls and landslides, and isolated liquefaction.
VII	Frightens most; some lose balance.	Heavy furniture overturned.	Damage negligible in buildings of good design and construction, but considerable in some poorly built or badly designed structures; weak chimneys broken at roof line, fall of unbraced parapets.	Tree damage, rockfalls, landslides, and liquefaction are more severe and widespread wiht increasing intensity.
VIII	Many find it difficult to stand.	Very heavy furniture moves conspicuously.	Damage slight in buildings designed to be earthquake resistant, but severe in some poorly built structures. Widespread fall of chimneys and monuments.	
IX	Some forcibly thrown to the ground.		Damage considerable in some buildings designed to be earthquake resistant; buildings shift off foundations if not bolted to them.	
X			Most ordinary masonry structures collapse; damage moderate to severe in many buildings designed to be earthquake resistant.	

Figure 22: The Modified Mercalli scale (Credit: https://www.usgs.gov/media/images/modified-mercalli-intensity-mmi-scale-assigns-intensities)

- Richter Scale
  - In use from 1935 to about 1970, the Richter Scale uses a formula much like the MSS to calculate quake magnitude.
  - Phased out because it was accurate only for earthquakes in southern California and for quakes that occurred within 370 miles of a recording device.
  - The equations are still used in a limited sense, for forecasting earthquakes and their hazards.
  - The Richter magnitude formula is:

$$log_{10}E = 4.4 + 1.5M$$

    Where:
    E = the released energy in joules
    M = the Richter magnitude of an earthquake

4.4 Seismic waves

When earthquakes release their stored energy, it travels through the crust in the form of seismic waves. These waves can be classified into 4 main types - S, P, Rayleigh, and Love. S and P are the most important wave types, called "body waves," while Rayleigh and Love waves are collectively referred to as "surface waves."

P waves P types are the fastest traveling waves released by earthquakes. They are compressional waves - that is, their particle motion is parallel to their direction of propagation. Think of pushing a slinky - the coils bunch up, while the bunched section travels along the length. This is what happens when P waves pass through the Earth - it compresses the ground, shaking it horizontally. As it compresses the medium it passes through, P waves can travel through all material states - solid, liquid, or gas - meaning it has no problem passing through the liquid outer core of Earth.

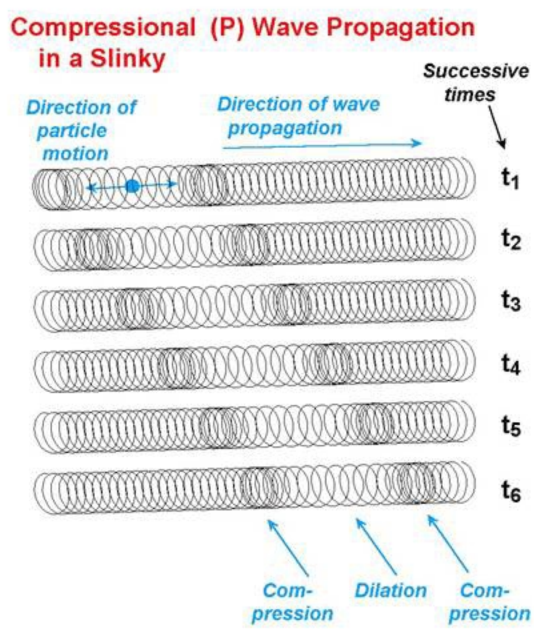


Figure 23: Compressional waves in a slinky (Credit: http://stem-works.com/external/activity/145)

S waves S waves are the second fastest waves released by earthquakes. They are transverse waves, meaning their particle motion is perpendicular to their direction of propagation. Think of swinging a slinky - the wave it creates moves up and down, traveling the length of the slinky. This is what happens when S waves pass through the earth - it vibrates the ground, shaking it vertically. As it shears the material it moves through, it requires resistance for its energy to be transferred. This is why S waves cannot pass through the outer core - its liquid state prevents shear wave propagation.

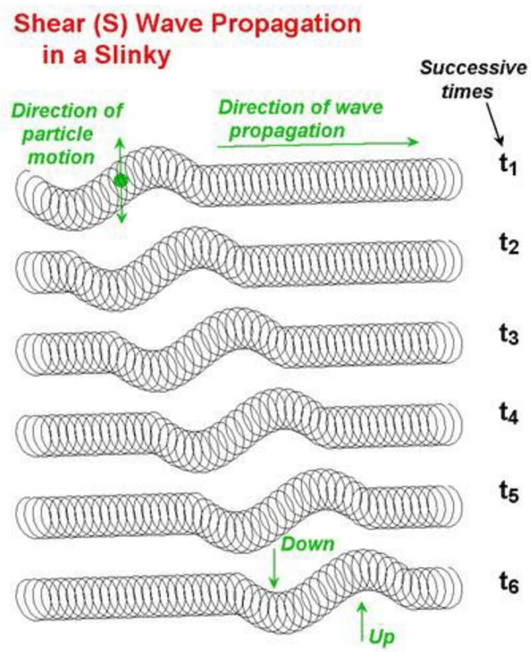


Figure 24: Transverse waves in a slinky (Credit: https://www.mtu.edu/geo/community/seismology/learn/seismology-study/make-body-wave/)

Surface waves Love and Rayleigh waves, collectively referred to as "surface waves," are the slowest of the four types. While S and P waves can move through the interior of the Earth, surface waves are just that - they travel only aboveground. Love waves shake the ground from side to side, while Rayleigh waves roll the ground in circles, like a wave in the ocean. The strength of these waves decreases at depth, so much so that mine workers often can't feel them!

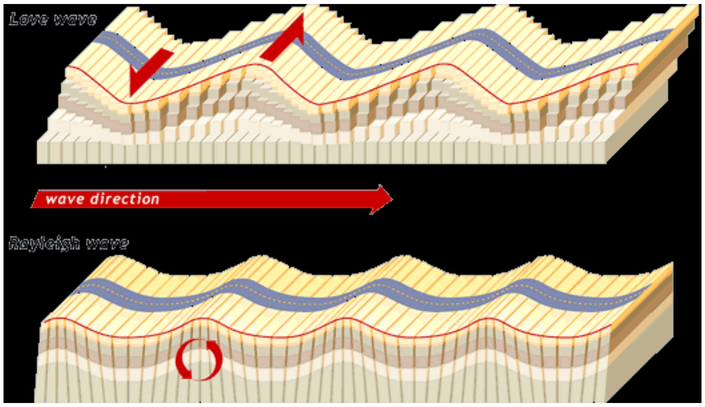


Figure 25: Surface waves illustration (Credit: https://www.exploratorium.edu/faultline/activezone/slides/rlwaves-slide.html)

4.4.1 P and S wave speed

P and S waves both travel faster through denser, harder material. This is why the speed of body waves changes as they move through the interior of the Earth - different layers of the planet have different compositions, temperatures, and pressures, and so have differing structures. Even though P waves can move through the liquid outer core, they still slow down significantly when doing so, while S waves are blocked entirely.

When crossing through layers of different densities, all waves change direction depending on if they move from a denser to a thinner medium, or they do the reverse. This is why, when viewing a diagram of S and P wave paths through the Earth, the lines are curved - they are reflected and refracted by the different layers of the crust, core, and mantle.

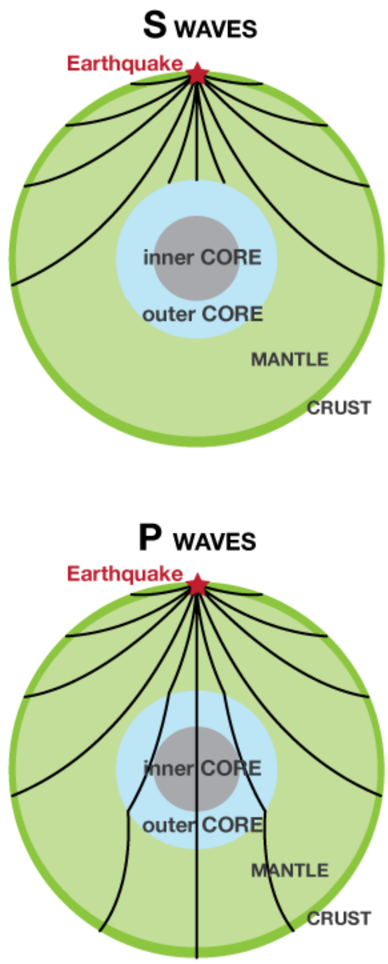
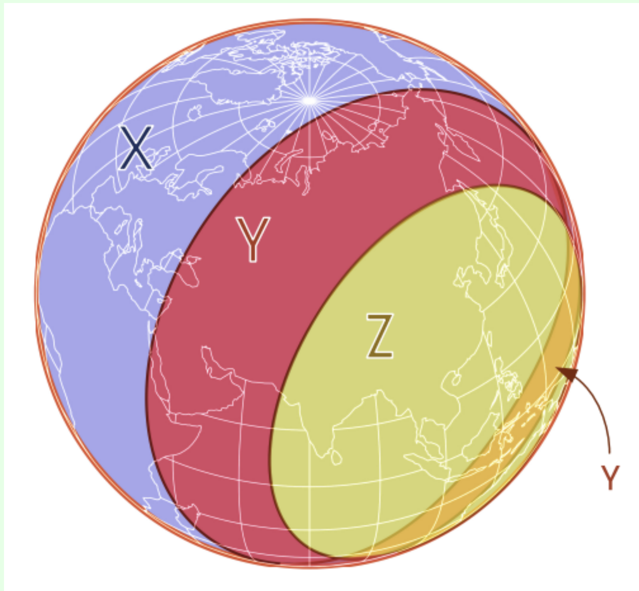


Figure 26: How the paths of seismic waves change in Earth's interior (Credit: https://www.usgs.gov/media/images/p-wave-and-s-wave-paths-through-earth)

This differing movement through different substances is also what makes some areas more high-risk to earthquakes than others. If a geographic region is underlain with loose sediment, while the low density will slow down earthquake waves and prevent them from spreading further, the flexible and ductile nature of the material will allow for more movement of the ground. The waves need less energy to move more earth - this leads to increased danger and damage to property. If a region is underlain with solid bedrock, while seismic waves will be spread further due to its high density, the brittle and inflexible nature of the material will prevent the worst of the waves' destruction. On the East Coast of the U.S., where underlying bedrock is common, a small earthquake in Virginia can be felt all the way in New York!

Example (2021 USESO Training Camp Geosphere Exam #6 amd #7)

The figure below divides Earth's surface into three regions according to the seismic waves (or lack thereof) that are observed in each after an earthquake. Note: the arrow points to a portion of region Y seen on the other side of the globe.



Where, approximately, did this earthquake most likely occur?
A. Southeast Asia
B. Off the coast of South America
C. Near the Mediterranean
D. The North Pole
E. The South Pole

Consider if the radius of the outer core was increased. Which of the following would be true?
I) Only P-waves would be observed in Y
II) Y would move towards X
III) Surface waves would be observed in Z
IV) Z would expand
A. I only
B. II only
C. I and III
D. II and IV
E. II, III, and IV

Solutions:
For the first question, notice that X shows where both P- and S-waves occur, Y represents the

P-wave shadow zone, and Y and Z comprise the S-wave shadow zone. One may see that the earthquake occurred in the center of X. The only plausible answer is B.

For the second question, like in the previous question, this answer is most clear using a two-dimensional view of seismic wave rays. I is false because both P- and S-waves are refracted back to the surface unobstructed. Meanwhile, the hypothetically larger outer core does obstruct their path such that the boundary between regions X and Y moves towards the center of X; II is true. III is false as surface waves would not reach the other side of the globe. Finally, IV is true because a larger core would create a larger area where core-refracted P-waves reach the surface.

4.5 Locating the center of an earthquake

Now we know what seismic waves are and how they are recorded, let's take a look at how they're used to find the center of an earthquake.

4.5.1 S and P travel times

As mentioned before, P waves travel faster than S waves. This difference in speed is a known quantity, which means the difference in arrival times from P to S waves at a certain seismograph can be used to calculate the distance from the machine to the center of the earthquake.

To do so, utilize a P and S wave chart. There are multiple types; however, each presents the same type of information, so learning to use one should be enough to make sense of the others.

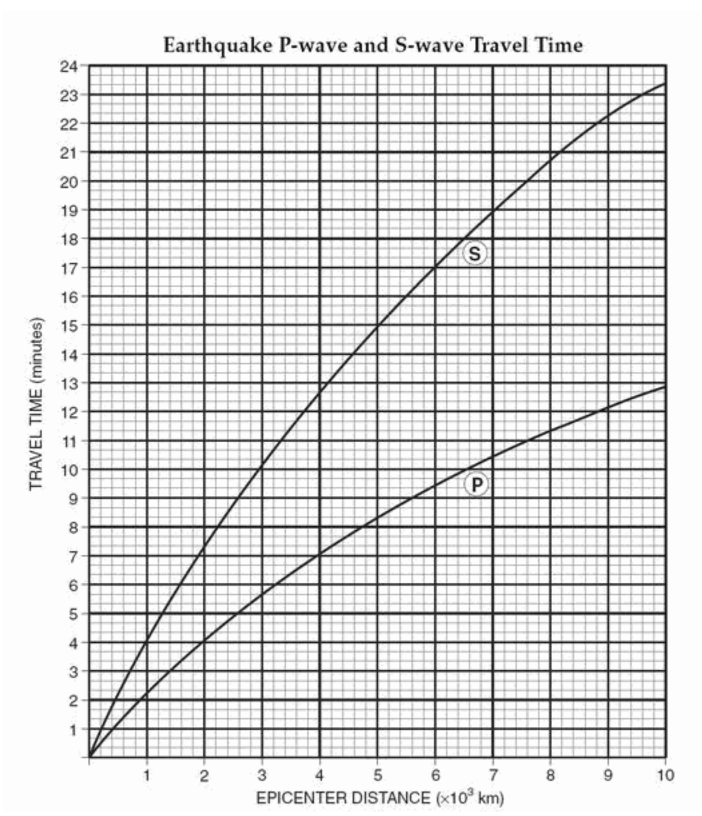


Figure 27: P and S wave arrival times (Credit: https://www.maplesoft.com/support/help/maple/view.aspx?path=MathApps%2FEpicenterOfEarthquakes)

To calculate the distance to the epicenter, first look at the provided seismogram. There should be two spikes. The first one should occur behind a period of equilibrium, which represents the time of P-wave arrival. The second spike should be larger and later in the day than the first, and represents the arrival of S-waves. You can disregard surface waves - they are not used in distance calculations.

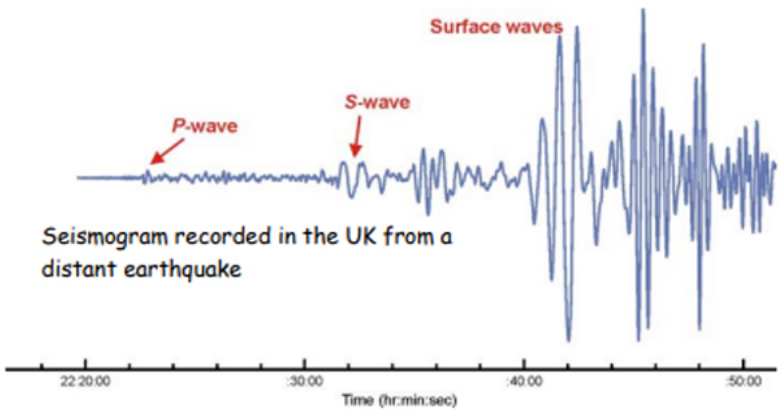


Figure 28: The seismogram of an earthquake in the UK (Credit: https://www.bgs.ac.uk/discovering-geology/earth-hazards/earthquakes/how-are-earthquakes-detected/)

1. Take the times of the two spikes and find their difference. In the figure above, it seems to be approximately 22:22:00 for P-wave arrival,and 22:31:00 for S-wave arrival. The difference between the two times is therefore 9 minutes.

2. Next, take a piece of paper, and set it up right next to the y-axis of the P and S wave arrival time chart. Make a mark at 0, and a mark at the appropriate difference in time - in our case, 9, as the units of the y-axis are in minutes.

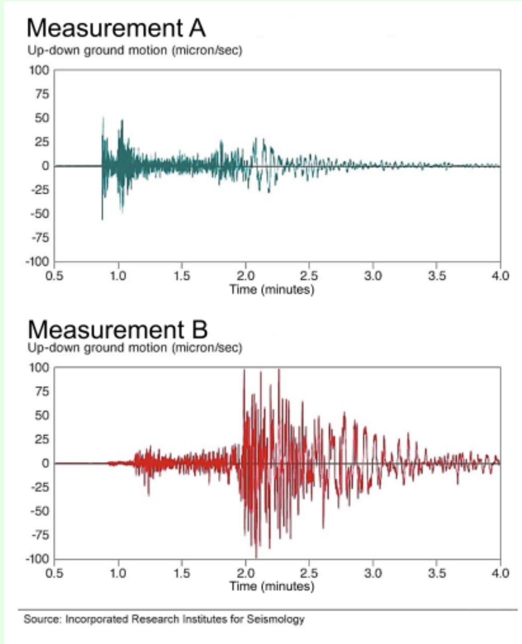
3. Take the marked up paper and slide the paper up along the P-wave arrival graph, making sure your 0 mark is aligned neatly with the P-wave line. When the tick you made at the 9 minute mark also aligns with the S-wave line, stop.

4. Note where the two marks matched up with the two lines. Now, do not remove your paper - trace the place you stopped down to the x-axis. Congratulations, you've found it! The x-value of the point it matched up is your distance to the epicenter of the quake, in the appropriate units.

Example (2022 USESO Training Camp Geosphere Exam #7)

The following image shows two seismograms, one of a nuclear test and one of an earthquake.

Which of the following correctly identifies the earthquake and gives the best evidence to support the claim?



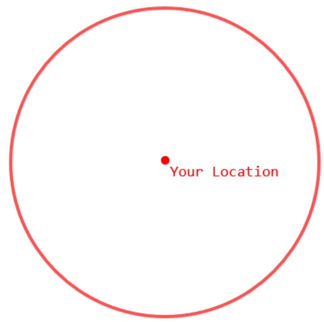
A. Measurement A is the earthquake, as evidenced by the clear gap between the arrival times of P and S waves at 0.8 and 1 minute respectively.
B. Measurement A is the earthquake, as evidenced by the much greater magnitude of P and S waves as compared to the surface waves.
C. Measurement B is the earthquake, as evidenced by the clear gap between the arrival times of P and S waves at approximately 1.1 and 1.9 minutes respectively.
D. Measurement B is the earthquake, as evidenced by the sudden increase in magnitude at the arrival of the surface waves after the arrival of P and S waves.

Solution: Surface waves generally arrive at seismometers with a much higher amplitude than P and S waves. The highest amplitude signals in Measurement A occur at the beginning of the event, indicating that the disturbance was at the surface. Meanwhile, in Measurement B surface waves arrive after the body waves as typical of earthquakes. Thus the answer is (D). (C) is not the best answer as the gap and timings of the P and S waves are not clear, especially contained to the significant increase in magnitude due to the arrival of the surface waves

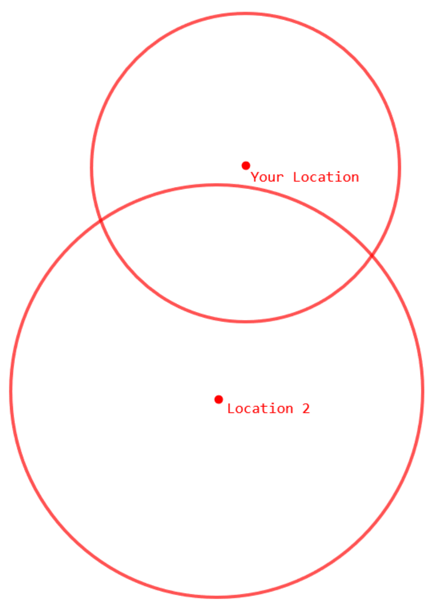
4.5.2 Triangulation

Knowing your distance to the center of an earthquake is all well and good, but there's a problem - you still don't know where, exactly, the earthquake took place. This is because you only have enough information to draw a circle around your location, whose edge is guaranteed to contain the epicenter.

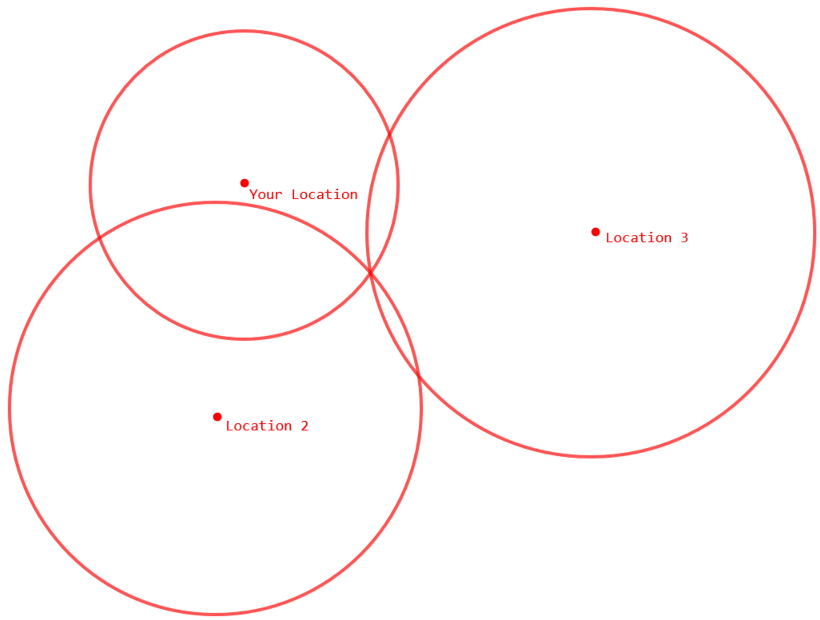
This might seem like a very difficult problem to solve. Your calculations can only get you so far, and guessing the location of an earthquake, even with the aid of the circle, seems unscientific. Luckily, you can get a more precise location with one simple trick - multiple circles!



With 1 distance, all you have is a range of possible locations around you where the epicenter could be located.



With two measured distances, you narrow down the possible locations to the two points of intersection of the circles.



With three distances, the intersection of the three circles is the location of the epicenter - which means, congratulations! You have found the center of the earthquake!

Note: If the readings are all from the same earthquake, as well as processed correctly, there should always be a unique point where the three circles intersect. If there is not, something has gone wrong - especially useful to know for multiple choice questions asking for feasible versus unfeasible triangulations!

5 Conclusion

Earthquakes, and the faults that cause them, are an integral part of our Earth's surface. They deal with the interactions between rocks - how they react when squeezed, stretched, and slid against each other, in all manners of direction and speed. A fault can be a slump in the side of a dirt knoll, inconveniencing at most a disgruntled farmer; or it can be the kind big enough to shake cities to their knees. Each destructive and disruptive earthquake can mean something new learned about the interior of the planet.

In the end, they are a part of our existence whether we like it or not. As such, it seems wise to familiarize ourselves with, educate ourselves on, and learn our lessons from them.