JOURNEY TO THE CENTER OF THE EARTH – Tutorial Script

This image shows a cross-section through Earth showing its main compositional and physical layers. How did scientists learn that this is what Earth's insides look like? We learned about Earth's composition by studying meteorites – the building blocks of Earth in the days of the early Solar System. Physical movements of Earth around our Sun and around our own rotational axis tell us about Earth's overall size and mass as well as how that mass is distributed (most of it in the center). To learn about the thickness and physical characteristics of each of Earth's layers, we study how earthquake waves travel through the Earth, a process similar to how X-rays are used to show us what's happening inside the human body. In this video tutorial, we will follow these earthquake waves as they journey towards and through the center of the Earth and demonstrate how they tell us some of what we know about Earth's insides.

In the Earthquakes video tutorial, we first learned about the waves produced during an earthquake that emanate out and through the earth: body waves, which consist of P (primary) and S (secondary) waves. Whenever there's fault rupture and stress is released, P and S waves emanate out from the focal point of the rupture and travel in all 3 directions. Body waves that travel downwards will travel deeper into the Earth, slowing or speeding up as they move from one layer into another, and eventually coming back to the surface to be felt and recorded on a seismograph. The time it takes for those waves to travel through the Earth, tells us about the layers through which they've traveled. Why the speeding up and slowing down?

We know from studying waves in natural and laboratory settings, that they slow down when they move into less rigid material and speed up when they move into more rigid material. As the velocity changes, the wave front will bend – upward if velocity increases, and downward if velocity decreases. Why? Because the first part of the wave that moves into new material will speed up or slow down depending on the changing rigidity while the other parts of the wave are still going the old speed. If one side of the wave speeds up, while the other is still going slower, the wave will bend upwards. If one side slows down while the other is still going faster, the wave will bend downwards.

Just traveling deeper within a single layer within the Earth, we would expect the higher pressures to make the rocks more rigid and hence the waves would gradually get faster and bend upward creating a general curved arc shape. In addition, whenever the waves cross a boundary, there would be a jump or drop in rigidity, and a consequent bend of the wave front.

After an earthquake, seismologists gather arrival times of P and S waves at seismographs across the planet, and based on the arrival times, they calculate the characteristics of the layers through which they traveled. Ultimately they turn those data into images such as these, which show the changes in velocity incurred within and across the various Earth layers.

We also know that P waves, which are compressional, can travel through all materials: solids, liquids, and gases. However, since solids are more rigid than liquids, and liquids more rigid than gases, they will travel faster through solids, slower through liquids, and slowest through gases. We see this with sound waves, which are also compressional. We'll hear a train coming towards us faster if we listen to the sounds emanating down the tracks, rather than the sounds coming through the air. S waves, on the other hand, are shear waves and can travel only through solids. When S waves travel into liquids, they disappear. We can use that valuable information to demonstrate how we know that Earth's outer core is liquid. After an earthquake, when we pick up the signals of P and S wave arrival times at seismograph stations, we see S waves arriving at stations within a 103° arc of the earthquake, but nothing in the 154° arc on the far side of the core. S waves are absent from those stations and thus produce a shadow zone. Why? When they cross into the liquid outer core, they get absorbed and can't travel any further. P waves, on the other hand, can travel through liquids and do arrive at stations opposite the core. However, P waves also have a shadow zone, in a donut shape. Why? P waves can travel through the outer core, but because it's less rigid than the solid mantle above it, the waves slow down, and that makes them bend downward, producing a zone with no P wave arrivals between the last P wave to travel through the base of the mantle, and the first to hit and bend downward into the outer core. We can use this valuable information of shadow zones to determine the precise location of our outer core. If the core were bigger, the shadow zones would also be bigger. If the core were smaller, so too would be the shadow zones.

With all this information in mind, let's take journey from Earth's surface to its core and see what happens to P and S waves as they interact with all Earth's layers during this journey. Remember first that body waves speed up or slow down when rock rigidity changes, and that rigidity could come from a number of physical or chemical changes. For example, we know that denser things sink and less dense things rise, so each layer we cross through as we travel deeper into the Earth will be denser than the layer above and less dense than the one below. However, being more dense doesn't necessarily translate to being more rigid. When body waves slow down as they enter the asthenosphere or outer core, they are still entering something more dense, just less rigid because the asthenosphere is plastic and the outer core liquid. Just keep that in mind during our journey!

So, starting at Earth's surface, we descend through the crust – a rigid layer that stays roughly uniform chemically throughout. However, the higher pressure that's encountered naturally with depth makes each deeper portion a bit more rigid than the portion above it. Thus seismic waves will gradually speed up as they travel through the crust, which means the wave front bends upwards. At the base of the crust, seismic waves will cross into a new compositional layer, the mantle. Both layers are solid, but the top of the mantle is denser than the base of the crust. All else being equal, this increased density does lead to increased rigidity. Therefore as seismic waves cross this boundary, they speed up and bend upward. Because of isostasy the base of the crust is deeper under continental crust, especially mountains, and closer to the surface under oceanic crust, especially the thinnest crust at seafloor spreading centers. Mohorovicic is the name of the scientist who first discovered this boundary using seismic waves and hence this boundary between the crust and the mantle is called the Moho.

As seismic waves continue to descend with the rigid part of the upper mantle (the mantle portion of the lithosphere or plates), the increasing pressure creates increasing rigidity and there's a slow and steady increase in seismic wave velocity with the wave front bending upwards. When the waves hit the boundary between the lithosphere and the asthenosphere, seismic waves drop in velocity considerably and the wave front bends downwards. Since both P and S waves travel through the asthenosphere we know it's solid, but the big drop in velocity indicates it's much less rigid than the lithosphere. Even though the pressures are higher here, so too is the temperature, and that brings these rocks very close to their melting point, so much so that they behave like a plastic. We call this low-velocity layer the asthenosphere, and over long periods of time it can flow and convect and thus helps drive the breakup and movement of the overlying lithosphere or plates.

As seismic waves continue to descend within the asthenosphere, the increasing pressure creates increasing rigidity and there's a slow and steady increase in seismic wave velocity with the wave front bending upwards. Then we hit the transitional zone of the mantle, where many minerals have transformed under high pressures into denser forms – new minerals with more tightly packed atoms. We see a jump up in seismic wave velocity here with wave fronts bending upwards.

As seismic waves continue to descend within and past the transitional zone through the lower mantle, the increasing pressure creates increasing rigidity and there's a slow and steady increase in seismic wave velocity with wave fronts bending upwards. About halfway to the center of the Earth, we cross the boundary with the liquid iron outer core. S waves disappear completely. P wave velocity drops considerably with the wave front bending downwards.

As seismic waves continue to descend within the outer core, the increasing pressure creates increasing rigidity and there's a slow and steady increase in seismic wave velocity with the wave front bending upwards until we cross the boundary with the inner core, which is solid iron. Here P-waves increase their velocity and their wave front bends upwards.

Seismic waves that make it all the way to the center of the Earth will keep moving and rise upwards again towards the surface doing the same thing they did on the way down but in reverse, speeding up or slowing down as they go upward through and across each layer.

Seismologists use these earthquake body waves to understand many things about what's happening inside the Earth, from the thickness and rigidity of the layers through to the core, to the presence in the crust of magma bodies, oil and water reservoirs, and mineral deposits.

[end credits]

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