EarthScope Consortium presents “**Deep Earthquakes** (https://www.iris.edu/hq/inclass/animation/859 )

Text from the animation:

The majority of earthquakes occur at less than 100 km depth while deeper earthquakes occur in few locations world wide. Why is that?

As we explore earthquake depths in and around the Pacific Ocean Basin, we find some areas with only shallow earthquakes and other regions with earthquakes down to 700 km.

In this animation, we will investigate why spreading ocean ridges and transform faults have only shallow earthquakes whereas subduction zones can produce earthquakes hundreds of kilometers deep.

We will discover that young oceanic plates near spreading ridges are hotter than older oceanic plates, for example, in the western Pacific Ocean. And how the temperature of a plate controls its ability to produce earthquakes.

Remember that lithospheric plates, also called tectonic plates, have a layer of crust on top of lithospheric mantle, the outermost rigid part of the mantle. These move as a single unit. The hotter asthenosphere beneath the plates is solid but less-rigid mantle rock that can slowly flow.

Let’s examine the formation of new ocean plate and how that plate cools with age. As hot mantle rock rises to lower pressure, a small portion of this upwelling asthenosphere melts to form magma that builds the 7-km-thick oceanic crust at the edges of two diverging plates along the ridge axis. The oceanic crust maintains its thickness during migration away from the ridge and has chemistry distinct from the underlying lithospheric mantle. Beneath the spreading ridge, there is only a thin layer of lithospheric mantle because it is unusually hot in the upwelling zone. As the plate slowly moves away from the ridge, it cools by conducting heat through the crust to the cold ocean water above. At the same time, the underlying asthenosphere cools and adds to the bottom of the lithospheric plate. Mathematical modeling of this cooling process illustrates the ocean plate becoming cooler and thicker with age. The temperature at the bottom of the plate is about 1300°C. Notice that most of the cooling process occurs between age zero at the ridge and about 80 million years when the ocean plate has grown to about 100 km thick. The upper part of the plate, where the temperature is less than 600°C, is the only part cold and brittle enough to fracture and produce earthquakes. Though still rigid, the lower plate is warmer and can deform in a ductile or plastic fashion.

So, the spreading centers and transform faults of the East Pacific Rise, Chile Ridge, and Galapagos Ridge in the eastern Pacific Ocean have only shallow earthquakes. Similarly, in the Atlantic Ocean, only shallow earthquakes are found along the Mid-Atlantic Ridge. Shallow earthquakes can occur at all plate boundaries and even occasionally in the middle of oceanic plates.

Now let’s tackle the deeper question of **how** earthquakes can occur hundreds of kilometers deep in subduction zones.

We’ll start by considering a 30-million-year-old ocean plate, which we’ll call a slab, subducting at 5 cm/yr into hotter asthenospheric mantle beneath a continental plate. As the ocean plate subducts, the warming process takes many millions of years as the slab descends. The deeper part of it is continuously replaced, in a conveyor-belt fashion, by cooler plate from above. Mathematical modeling again illustrates the temperatures within the subducting ocean plate. In this example, lithospheric mantle rock in the subducting plate at 150 km depth is ***1000°C*** cooler than the asthenospheric mantle at the same depth. Earthquakes occur on the shallow part of the boundary between the converging plates and within the shallow parts of both plates near that boundary. In addition, there is a zone of rock cooler than 600°C within the subducting plate that remains brittle and within which earthquakes can occur to depths of hundreds of kilometers.

Let’s explore three subduction zones that have progressively deeper earthquakes: Cascadia with earthquakes to 65 km depth; Central America with earthquakes down to 250 km depth; and Tonga with earthquakes to 700 km deep.

Along the Cascadia Subduction Zone near Vancouver Island, the Juan de Fuca Plate is only 6 million years old and subducts at 5 cm/yr. Because it is very young and thin, Juan de Fuca Plate warms quickly during subduction. So, the upper portion of the subducting plate remains brittle and able to produce earthquakes to only 65 km depth.

Along the Central America Trench where earthquakes reach about 250 km depth, the age of the oceanic Cocos Plate is only about 20 million years and it subducts at a rate of 8.5 cm/yr. Because it is young, the Cocos Plate is only 65 km thick. The resulting thermal structure of the subduction zone across Costa Rica shows brittle Cocos Plate lithosphere reaching over 200 km depth consistent with the observed maximum earthquake depth of about 250 km.

Now let’s consider subduction zones of the western Pacific where most deep earthquakes occur. Here the subducting Pacific Plate is up to 150 million years old.At the Tonga subduction zone, the Pacific Plate is 140 million years old and it descends beneath Tonga at 8 cm/yr. This old and cold oceanic plate is over 100 km thick and its interior tongue of brittle oceanic lithosphere extends to 700 km depth. So, it’s no surprise that over one half of all earthquakes deeper than 300 km occur in the Tonga subduction zone.

With our new understanding of how seafloor spreading produces thin and hot oceanic plates, the shallow depths of earthquakes along worldwide spreading centers and transform fault systems make sense. Variations in maximum earthquake depths from one subduction zone to another result from differences in age of the subducting plate and its rate of subduction. Old and cold oceanic plates that are subducting rapidly can reach depths of 700 km with their interiors still brittle and capable of producing the deepest earthquakes.