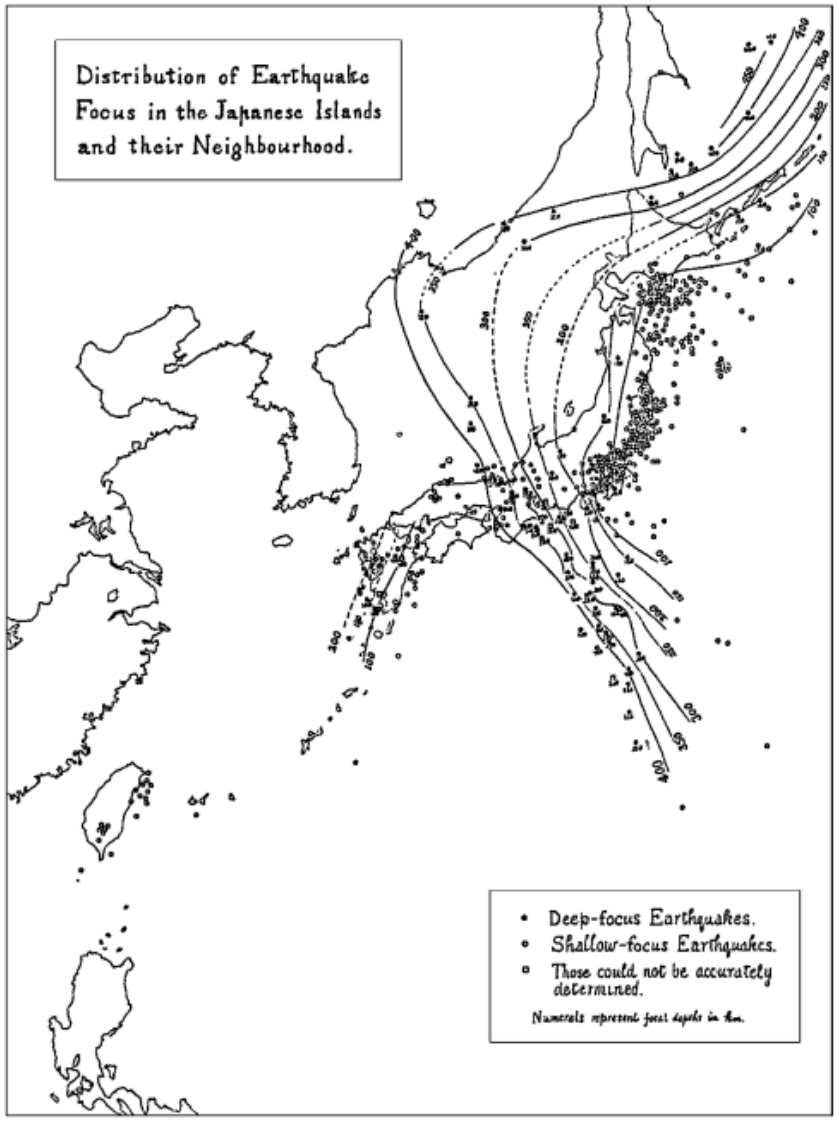
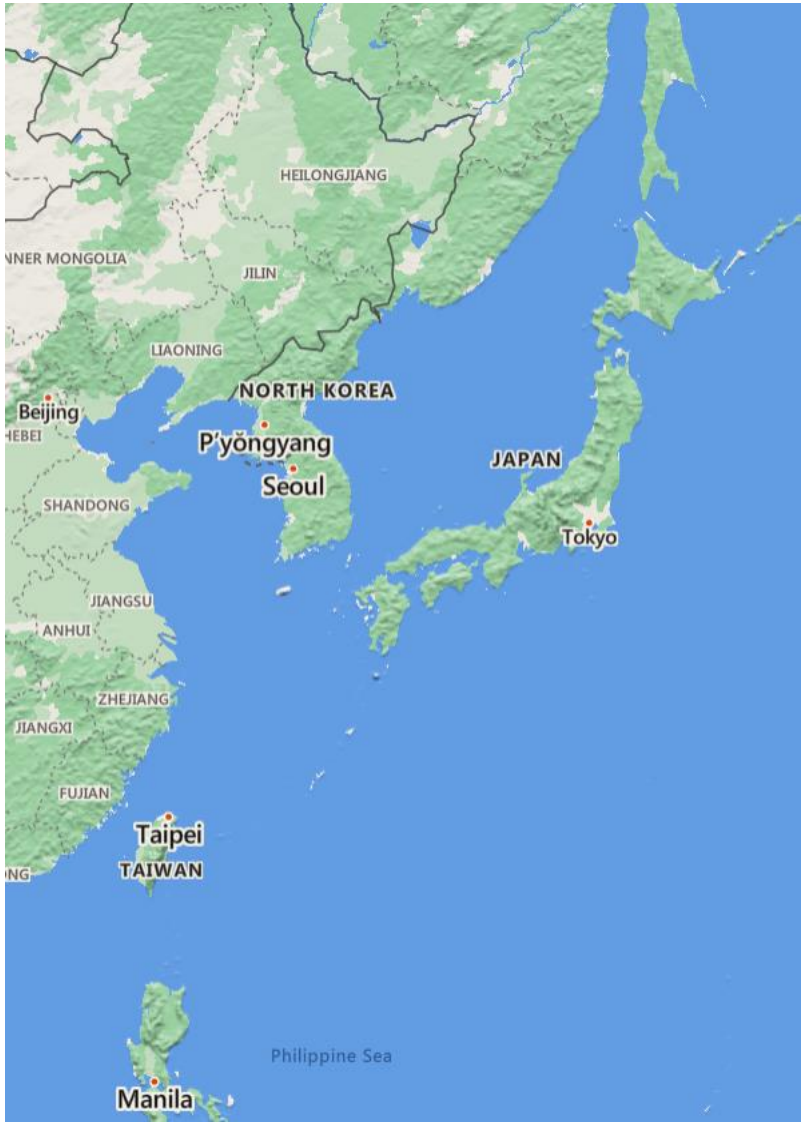
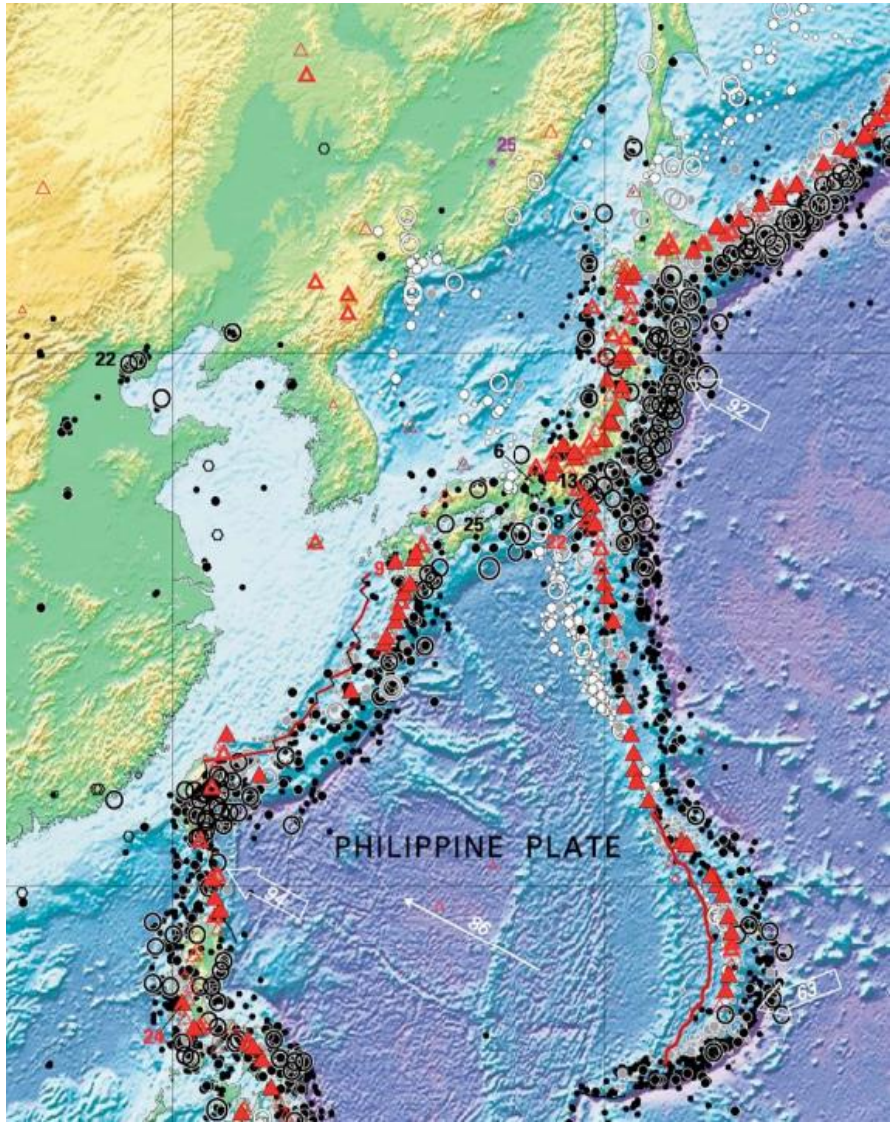






Subduction Zones and Earthquake Depth

(The What, The How and The Why)

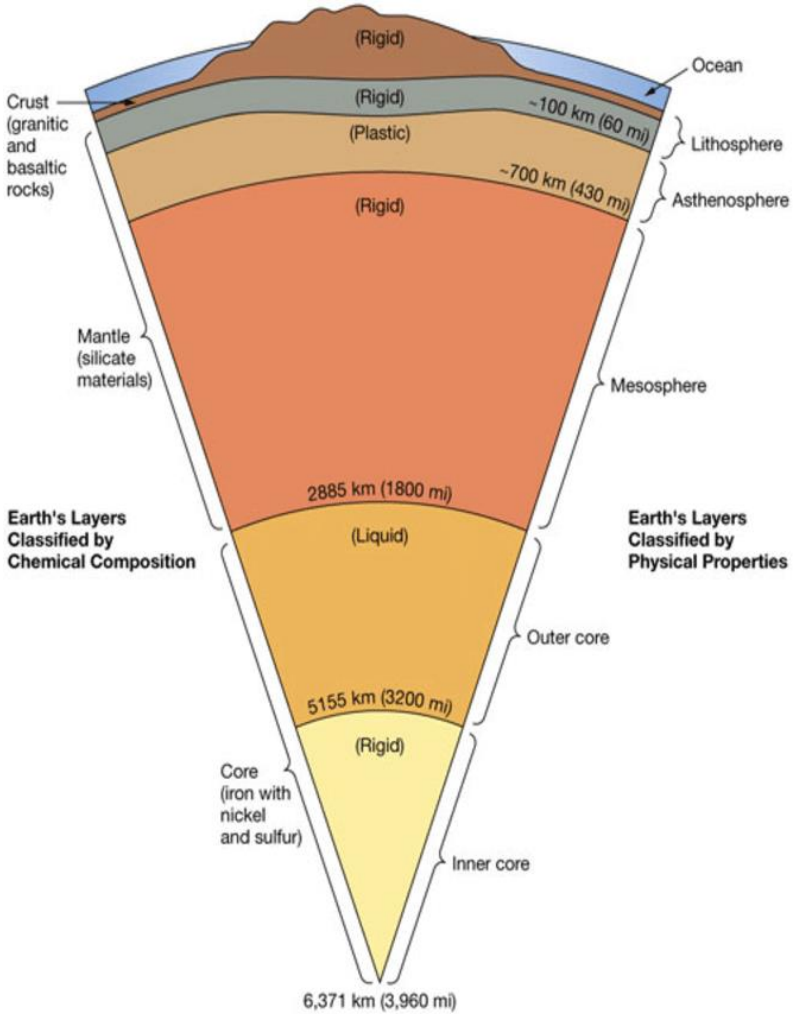
Before we start…..quick review of what we're starting with:

Chemical Model

Layers distinguished by chemical composition

Differences are *f*(density)

Can layers of different chemical composition have very similar physical (rheological) behavior? (answer: yes)



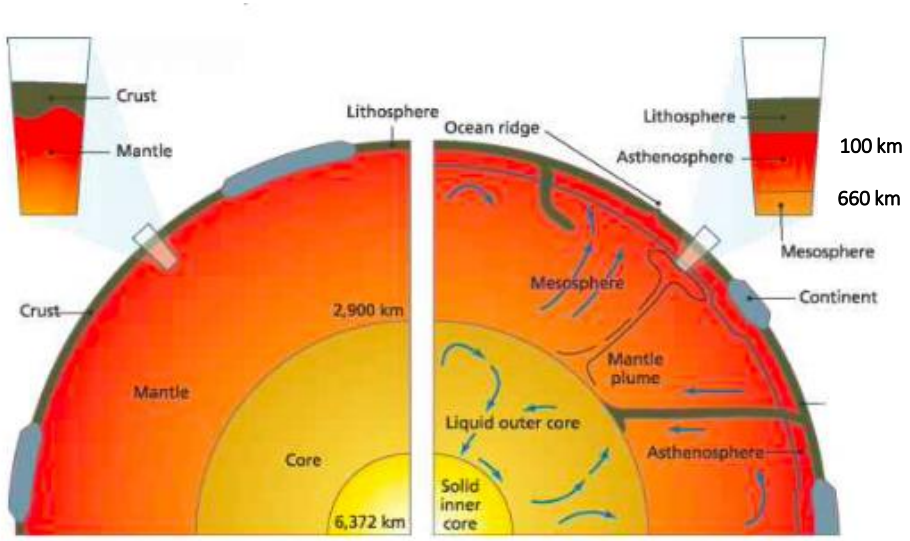
Physical (Rheological) Model

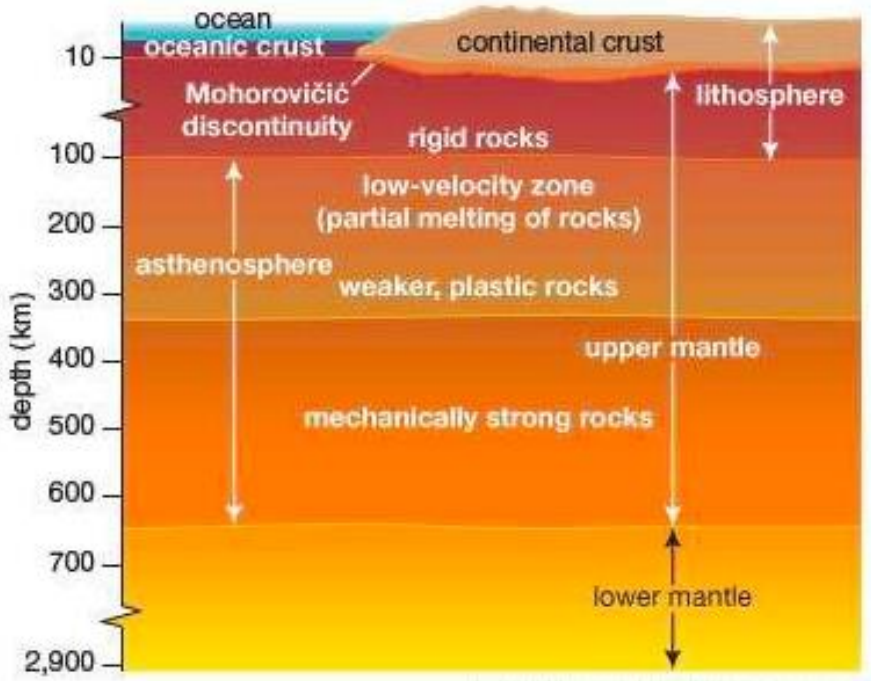
Layers distinguished by physical properties

Differences are *f*(plasticity)

Can layers of different physical (rheological) behavior have very similar chemical composition? (answer: also yes)

When we talk about subduction and earthquakes…

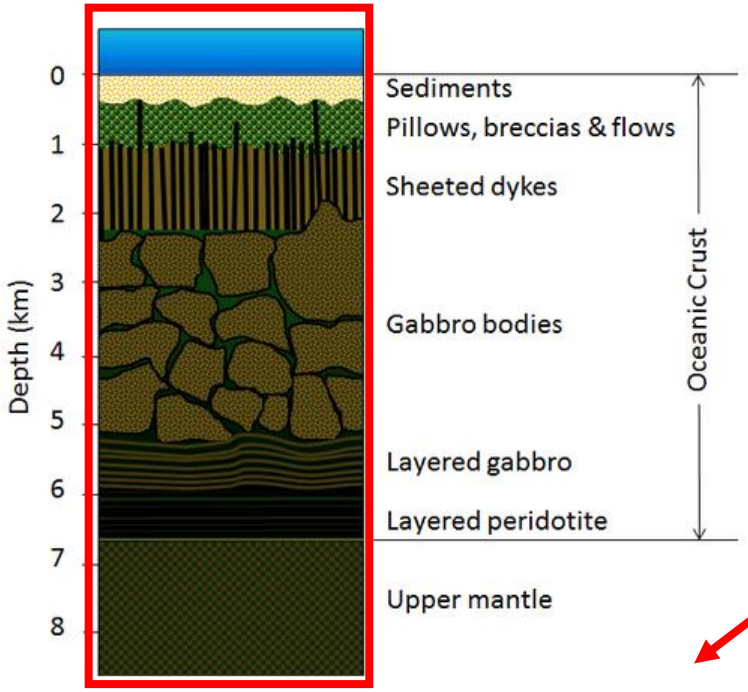


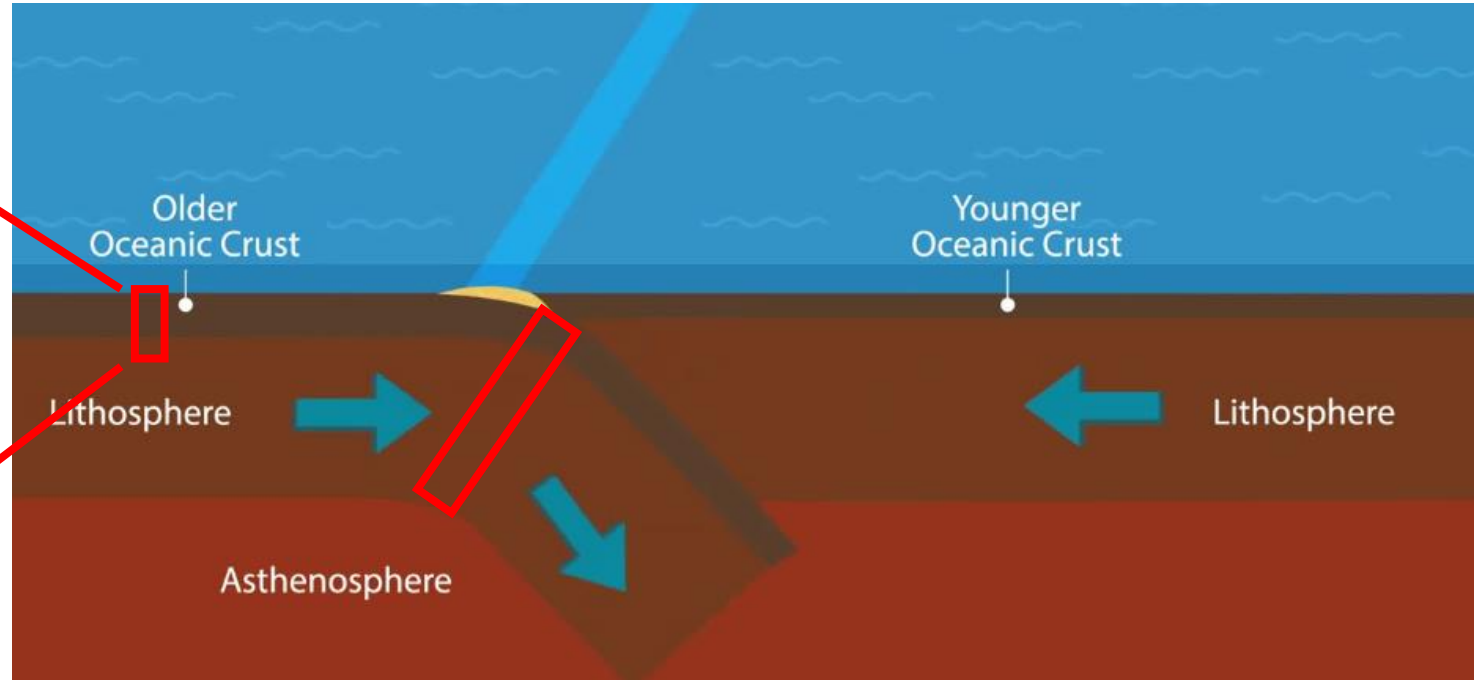


…we are talking about the interplay of the chemical and the physical properties of earth materials

Is it just the crust (chemical model) that subducts?

Nope! It's the lithosphere (physical model) that subducts.





Now we can start talking about earthquakes

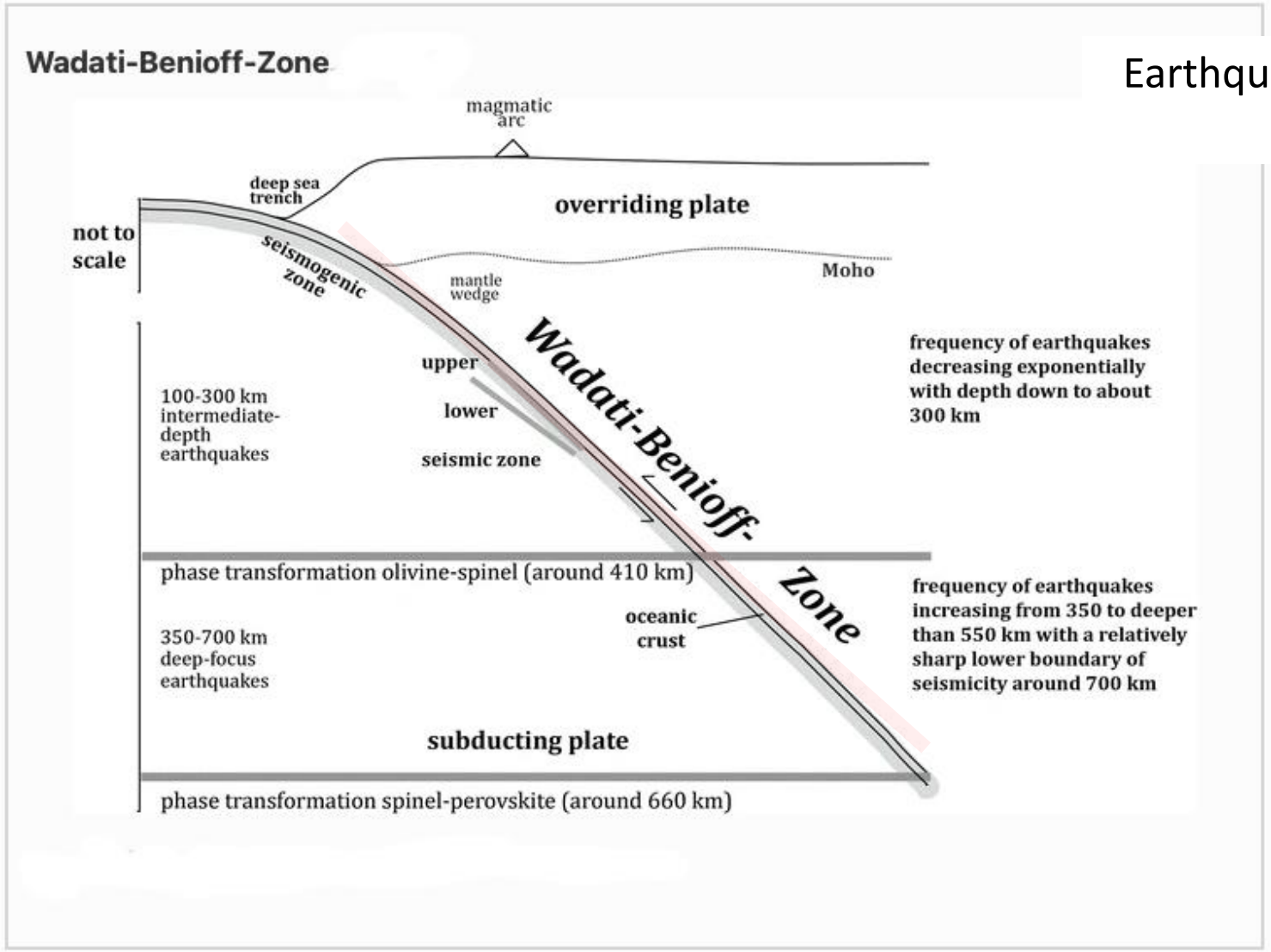
Kiyoo Wadati
(1902 – 1995)

Two researchers working on different continents using different tools to study earthquakes made two separate observations:

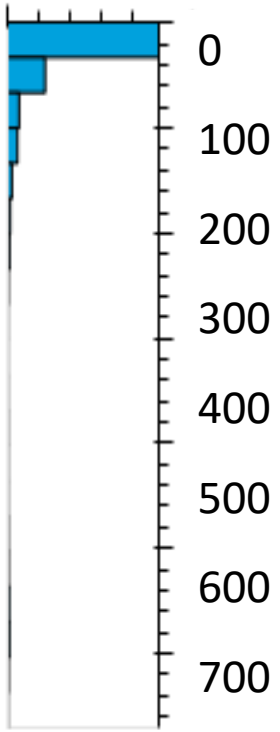
1. Earthquake depth under Japan slopes to the West such that deeper quakes are further West than shallower quakes (KW)

2. The location of quakes on a sloping plane is consistent with how it might look if they were (are) occurring along a subducting or submerged plate (HB)

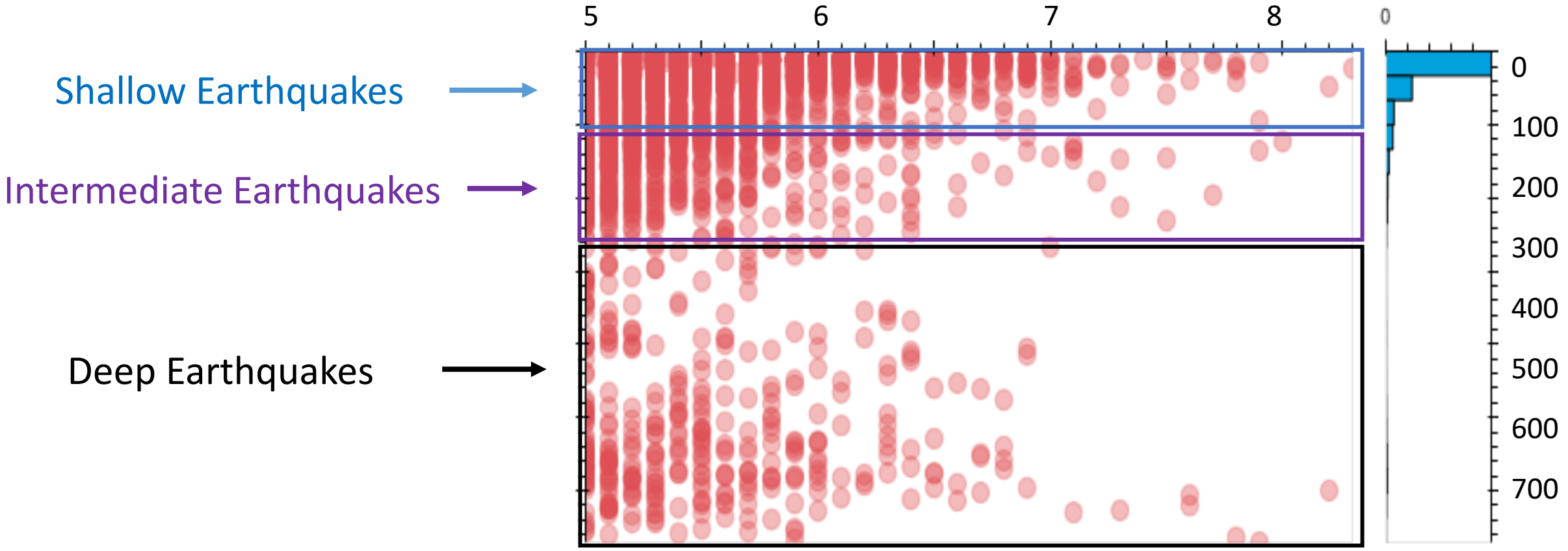
Hugo Benioff
(1899 – 1968)



Earthquake Frequency as *f*(Depth)



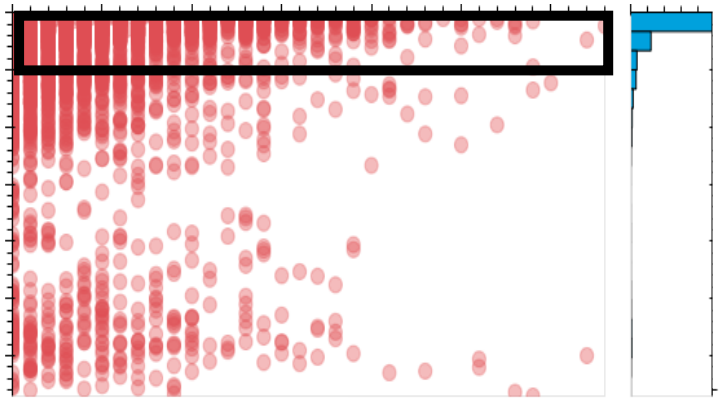
Are there relationships between earthquake frequency and magnitude (M) as *f*(depth)?



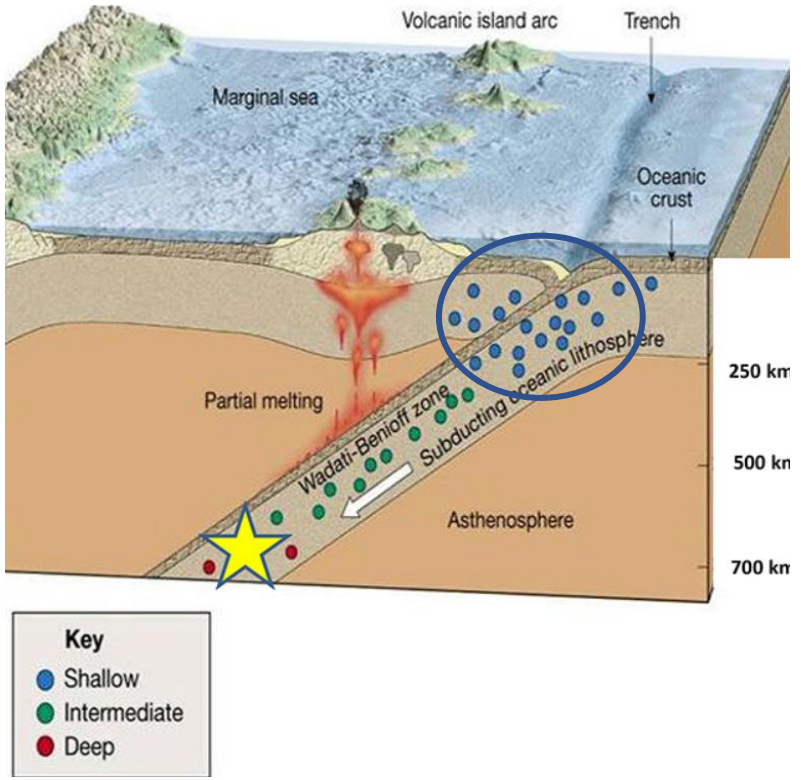
Wadati – Benioff Zone – What Do We See?

- Highest frequency of earthquakes are shallow (< 100 km) and the magnitude (Richter Scale) can vary significantly (M5 – M8+).
- Intermediate depth quakes (100 – 300 km) are less frequent and of lower magnitude (~ M6) than shallow quakes.
- Deep quakes (300 – 660 km) are more frequent than intermediate quakes, but less frequent than shallow quakes; the magnitude of deep quakes can be significant, but may (?) typically be ≤ M6
- Deep quakes are not equally frequent across that 300+ km interval; deepest of the deep quakes may be the strongest of the deep quakes

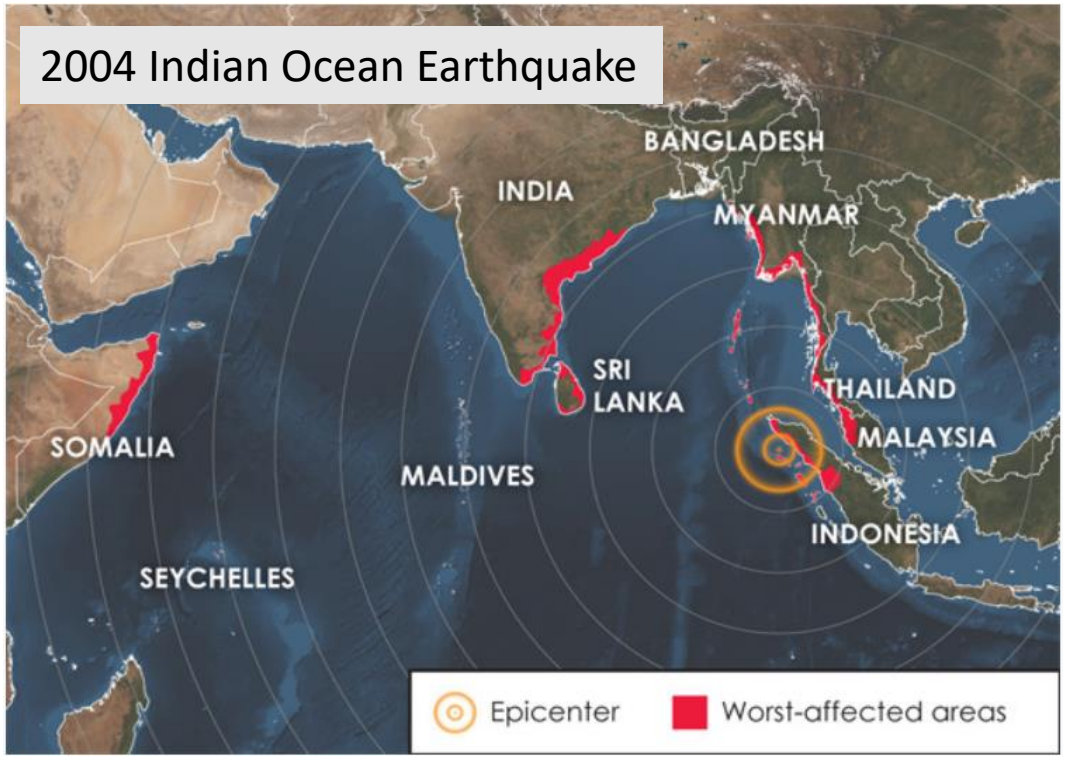
Shallow Subduction Earthquakes

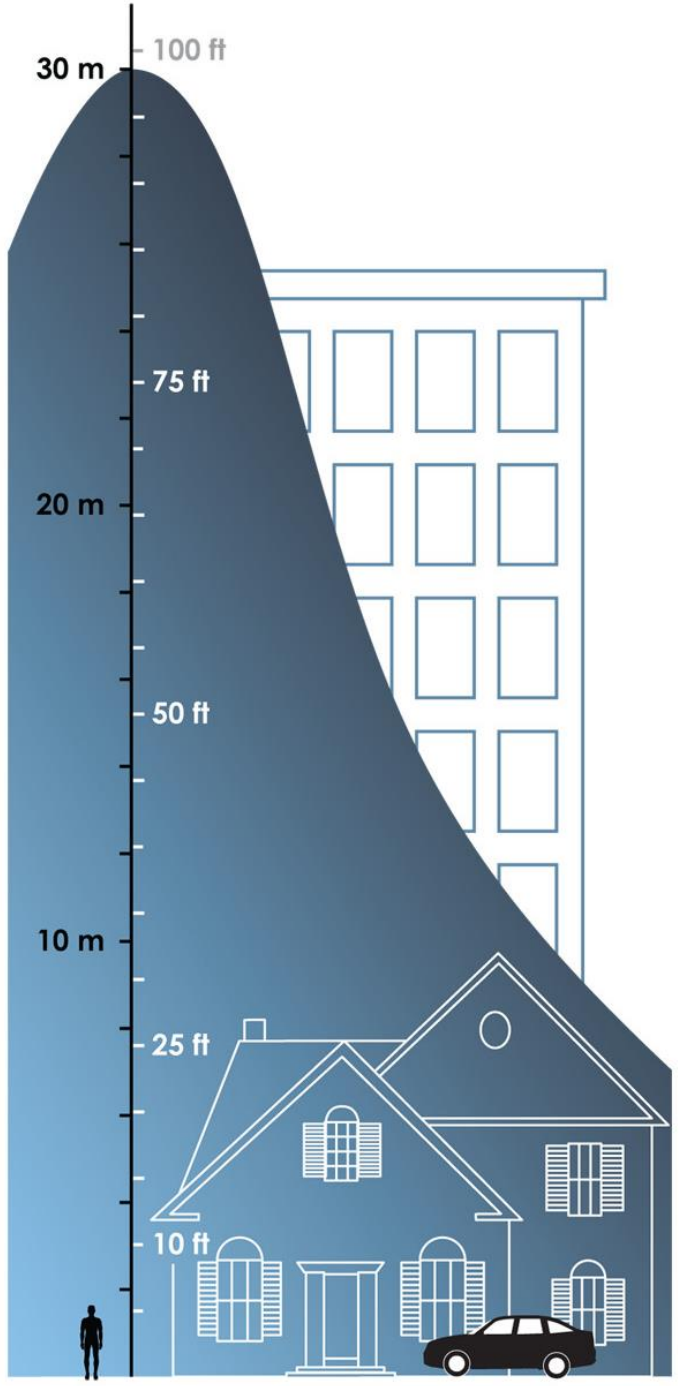


- Depth is consistent with lithospheric thickness – these are stress and rupture quakes during subduction
- Shallow subduction earthquakes occur at the contact of the two plates involved and are the result of compressional forces and resultant thrust displacement
- Most significantly associated with surface movement; can cause tsunami when vertical displacement occurs



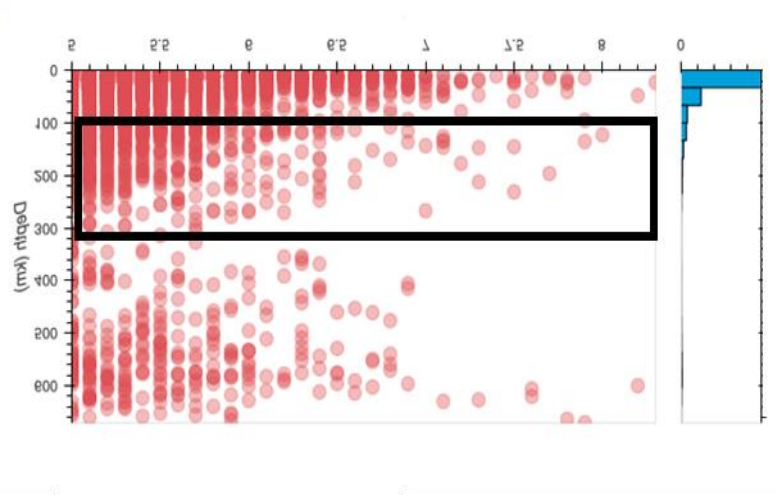
2004 Indian Ocean Earthquake

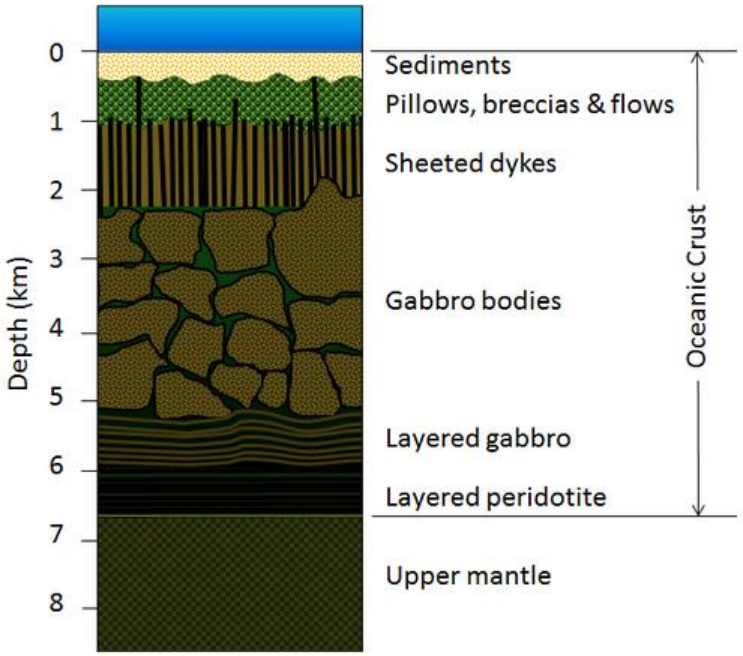




Intermediate Depth Earthquakes

- Result from the chemical transformation of oceanic crustal material on/in the downgoing plate during plate subduction (process is called *eclogitization*)





basalt (fine-grained gabbro)

gabbro (coarse-grained basalt)

+ P (a lot)

and T (some)

garnet-bearing eclogite

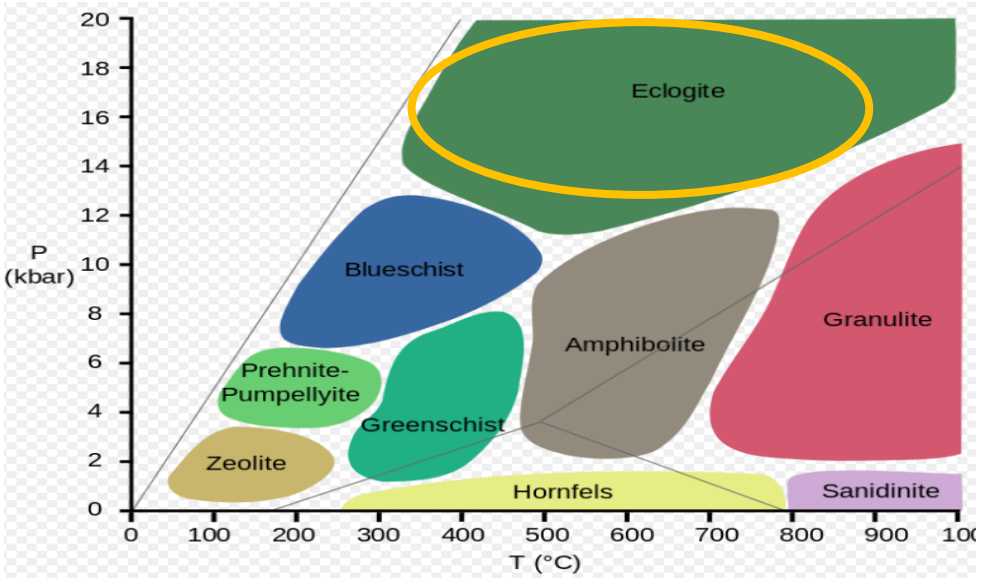
Why does this process cause earthquakes?

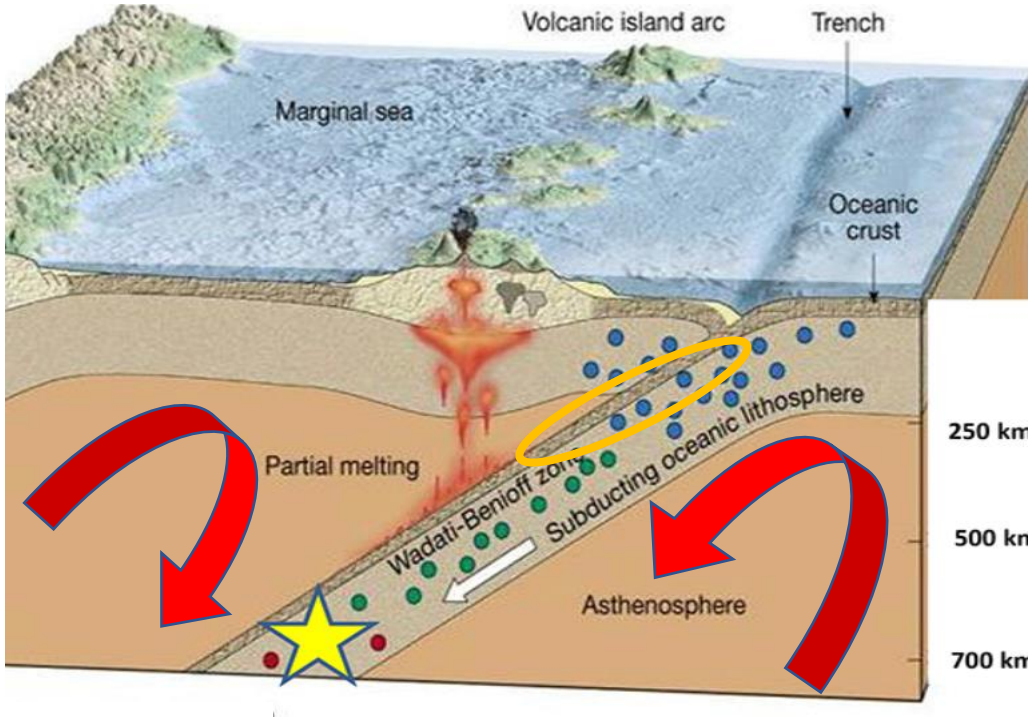
Tectonic pressure (P) & temperature (T) cause recrystallization (metamorphism) of crustal material within the slab as it's pulled down

Recrystallization of crustal material (basalt and gabbro) to eclogite leads to dewatering which can make the downgoing slab brittle

Brittle strain results in rupture of the crustal part of the subducting slab releasing energy

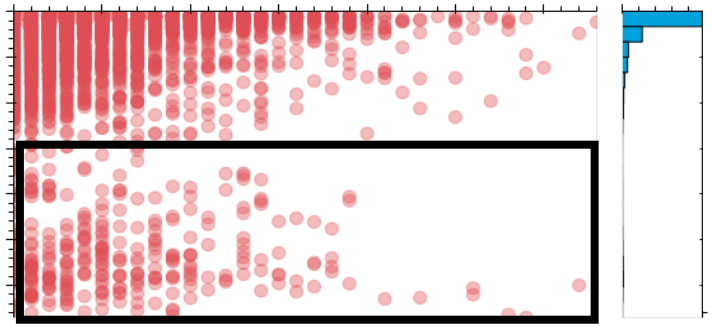
(recognize the momentum in subduction that is driving this process!)





Deep Earthquakes

- Result from chemical phase transformations of mantle material and resultant deformation and ‘avalanching’ of the subducting slab (in deep quakes the subducting plate itself can rupture!)



Olivine

+ P (a lot)

and T (some)

Spinel

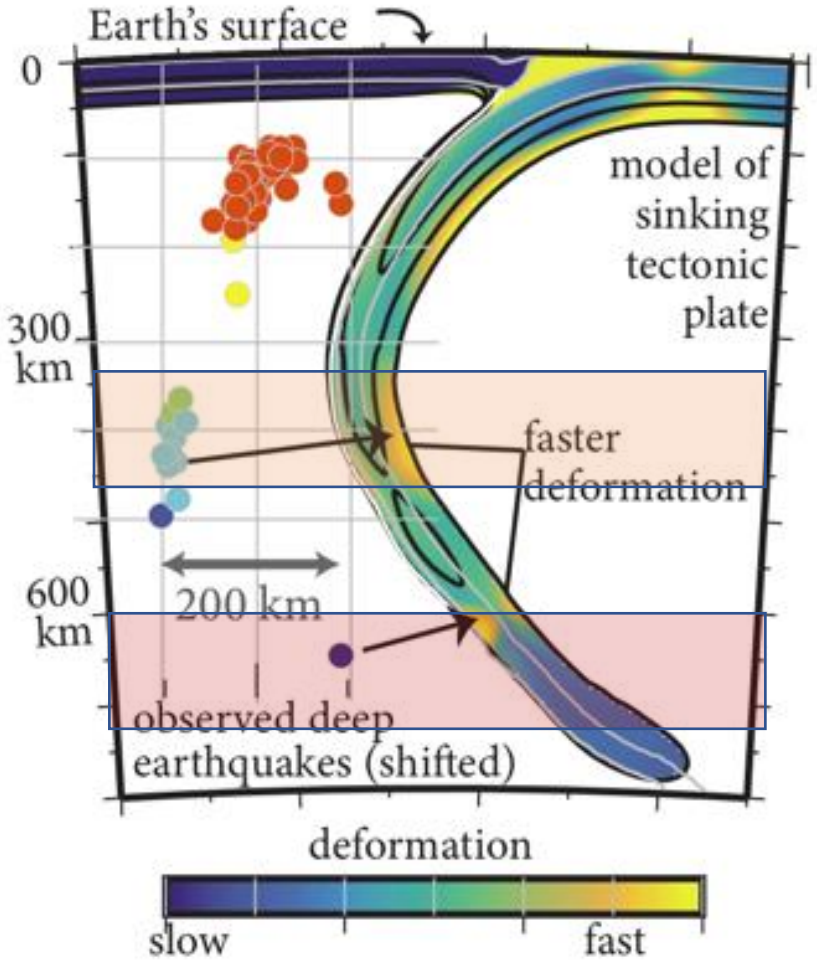
@ ~ 450 km deep

+ P (even more)

and T (more)

Perovskite

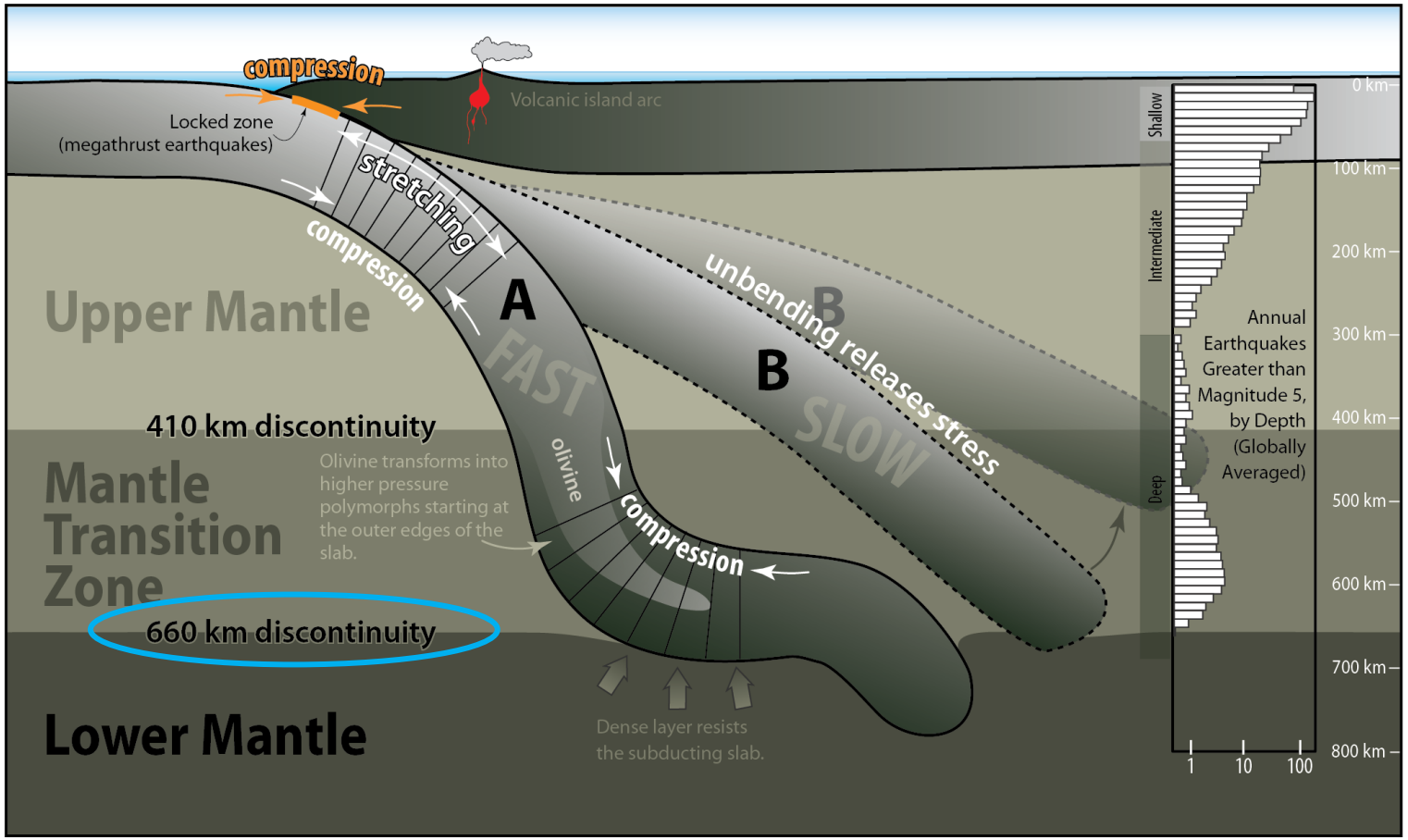
@ ~ 600 km deep



Olivine – Spinel Phase Transformation

Spinel – Perovskite Phase Transformation

Seismologists recognize that these very deep quakes are involving deformation within a subducting slab that can (or: *that appears to as based on modeling and seismic data*) penetrate the 660 km discontinuity at the base of the asthenosphere.

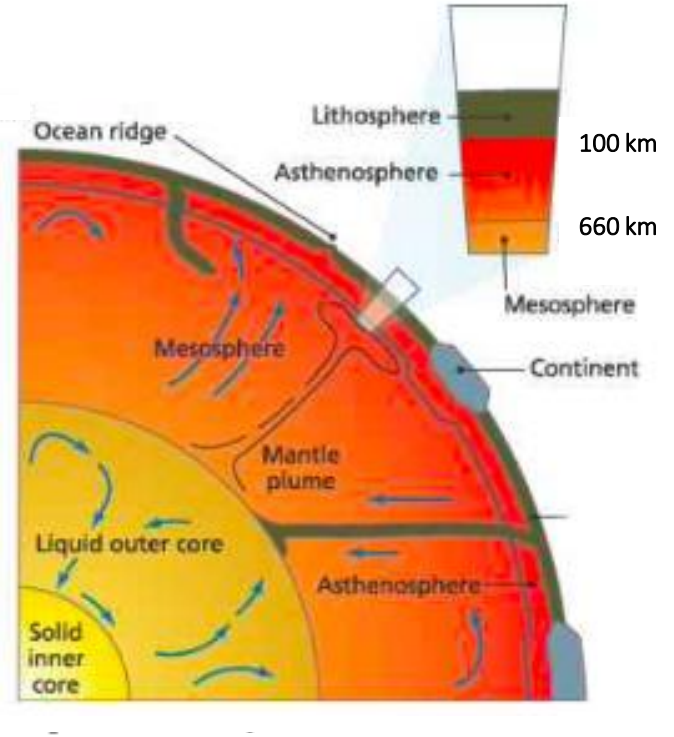


Billen, M.I. 2020. Deep slab seismicity limited by rate of deformation in the transition zone. Science Advances: 6 (22). 1-11.

Research Questions

(that aren't about earthquakes, but <u>are</u> about subduction processes….)

- Is penetration of the subducting slab into the mesosphere a deep driver of mantle convection?



- Are slab avalanches the cause of the deep mantle plumes that create flood basalts and large igneous provinces (and appear to be associated with significant extinction events in the geologic record)?