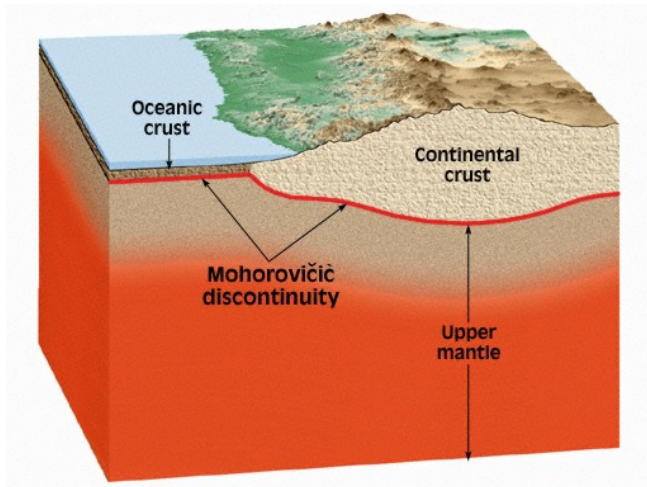


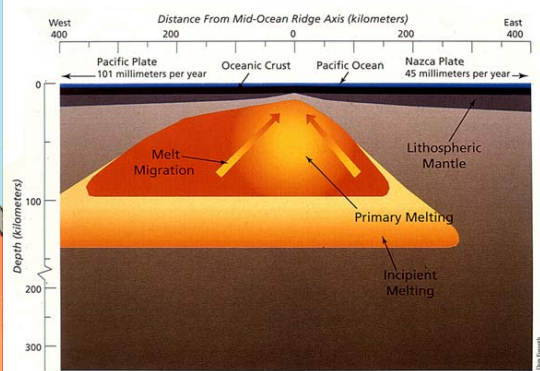
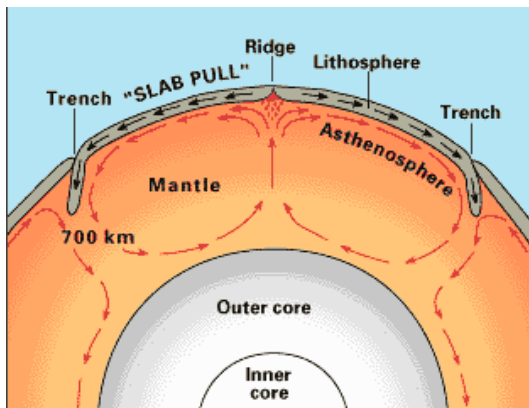
C3.3 The crust



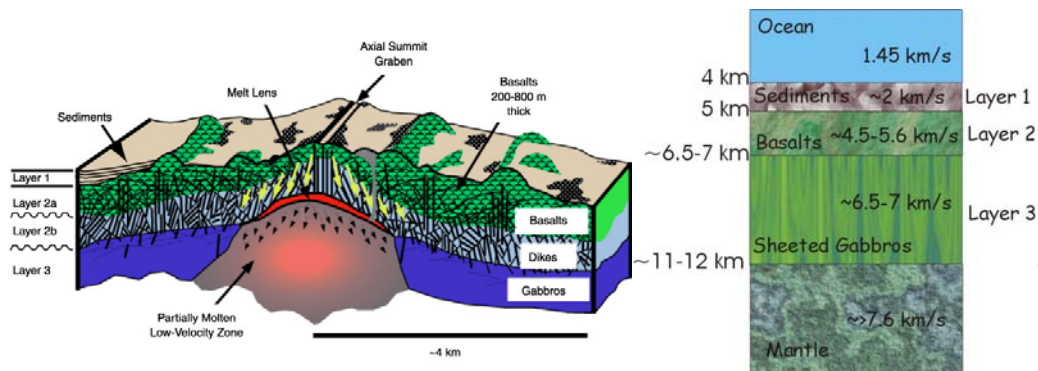
- The crust is formed by differentiation of mantle material.
- Crust is enriched in lighter elements compared to the mantle.
- Oceanic and continental crust are different in both thickness and composition.

C3.3.1 Oceanic crust

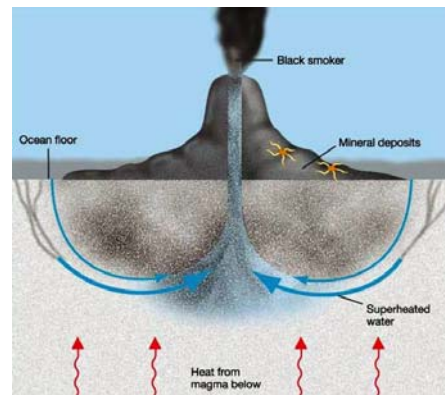
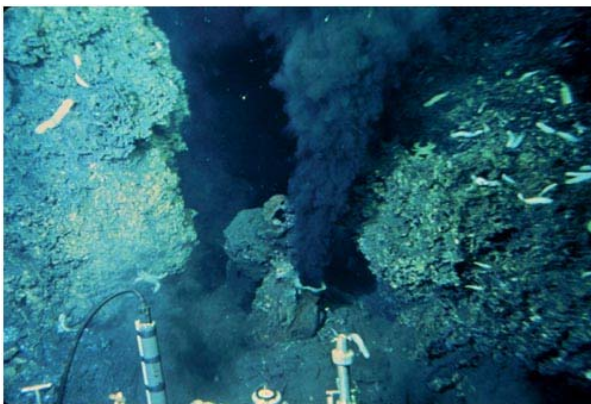
- Oceanic crust is 7-8 km thick and is formed at mid-ocean ridges through seafloor spreading.
- Spreading rates vary and can be up to 30 cm per year.
- Mid-ocean ridges are major underwater mountain ranges (East Pacific Rise, Mid-Atlantic ridge etc).
- As mantle material approaches the surface through convection, partial melting occurs through decompression.
- Melt is focussed to the ridge crest where it erupts to form new ocean crust.



- A magma chamber may exist (temporarily) beneath the ridge crest, depending on the rate at which the plates move apart. May comprise a thin melt lens overlain by a zone of partially molten mush.
- Structure of mid-ocean ridges can be investigated by seismic reflection and refraction studies (Fowler 9-5 and 9-26).
- Layered structure is well defined from seismic exploration (Fowler 9-5).
- Layer 1=sediments, layer 2= pillow basalts, layer 3 = gabbros and cumulates)
- Can also use low-frequency radio waves to image mid-ocean ridge structure.



- Seawater circulates through the oceanic crust and cools it. This also has a profound effect on the chemical composition of seawater.
- Seawater returns to sea floor through black smokers and other hydrothermal vents. First discovered in 1977 near the Galapagos Islands in the Eastern Pacific.

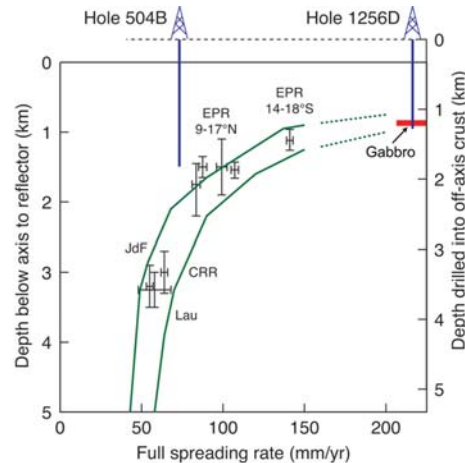


- Oceanic crust is sometime emplaced on land through tectonic processes and termed ophiolites (Fowler Figure 9-8). This allows a detailed geological study of the oceanic crust that is not possible *in situ*.

- Debate continues about how much the oceanic crust is altered by this emplacement process. i.e. are ophiolites typical of oceanic crust?
- Direct information about the ocean crust has come from scientific drilling (Fowler 9-3). First study made by the Glomar Challenger. More recent drilling programs operated by the ODP, IODP etc.



Joides Resolution



Wilson et al., (2006)

- An early attempt to drill to the mantle was Project Mohole

(http://en.wikipedia.org/wiki/Project_Mohole)

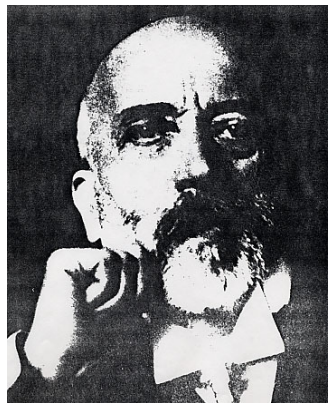
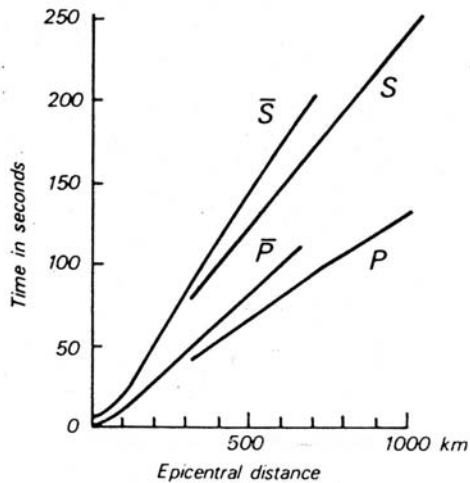
<http://www.globalsecurity.org/military/systems/ship/offshore-drillship-science.htm>

In 1957, two well-known oceanographers -- Walter Munk of the Scripps Institution of Oceanography in California and Harry Hess of Princeton University -- proposed developing a capability to drill deeply into the Earth beneath the seafloor, allowing oceanographers to sample the material below the boundary of Earth's crust and mantle, the Moho. Their efforts eventually led to Project Mohole, an attempt to acquire a ship that would let researchers drill into the Moho. Cost escalations eventually killed the project. Project Mohole was abandoned in 1966 because of lack of funding, without ever taking a sample of the Moho. Drilling in deep water presents some very interesting engineering problems that are really expensive to circumvent. The project was dropped in favor of the GloMar Challenger drilling project.

- To date, no drilling has reached the mantle.
- Hole 1256D reached the gabbro layer in Eastern Pacific (Wilson et al., 2006)

C3.3.2 Continental crust

- In 1910 Andrija Mohorovicic published a paper describing the time taken for earthquake waves to travel across the Balkans.
- He noticed that P-waves apparently travelled at two different velocities.
- He inferred that this required a crustal layer, underlain by a higher velocity layer. This boundary is now called the **Mohorovicic discontinuity** or Moho.



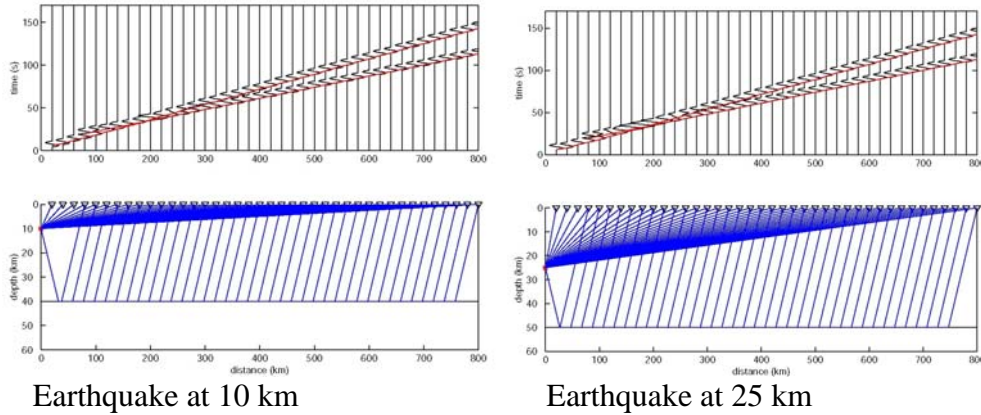
- What crustal velocity and crustal thickness is implied by the attached figure?
- In modern seismic terminology

$$P = P_n = \text{direct P-wave}$$

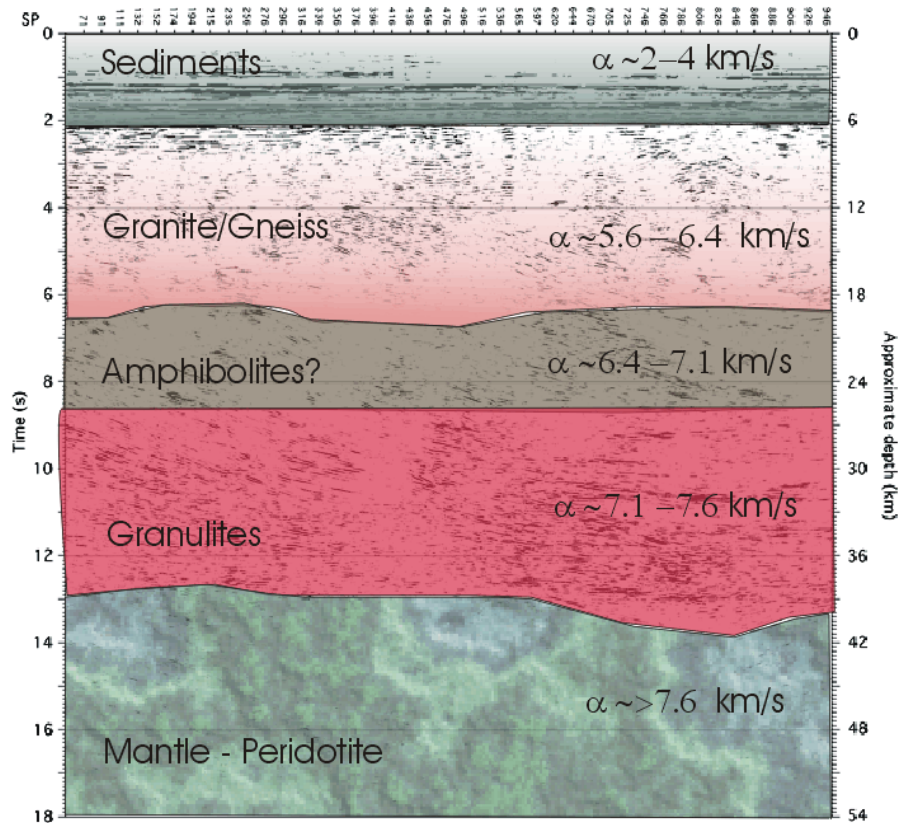
$$\bar{P} = P_g = \text{Refracted wave in mantle}$$

Demonstration with MATLAB script : `refract_v3_moho.m`

- Data show a direct wave (in crust) and a refraction travelling in the mantle. Model is adjusted until the data predicted by the model agree with the observed data.
- Red line is the measured data. The black lines (wiggles) show the prediction for the model.
- Note that we need to consider the fact that the earthquake did not occur at the surface. The depth of the earthquake is a parameter that must be varied to fit the data.

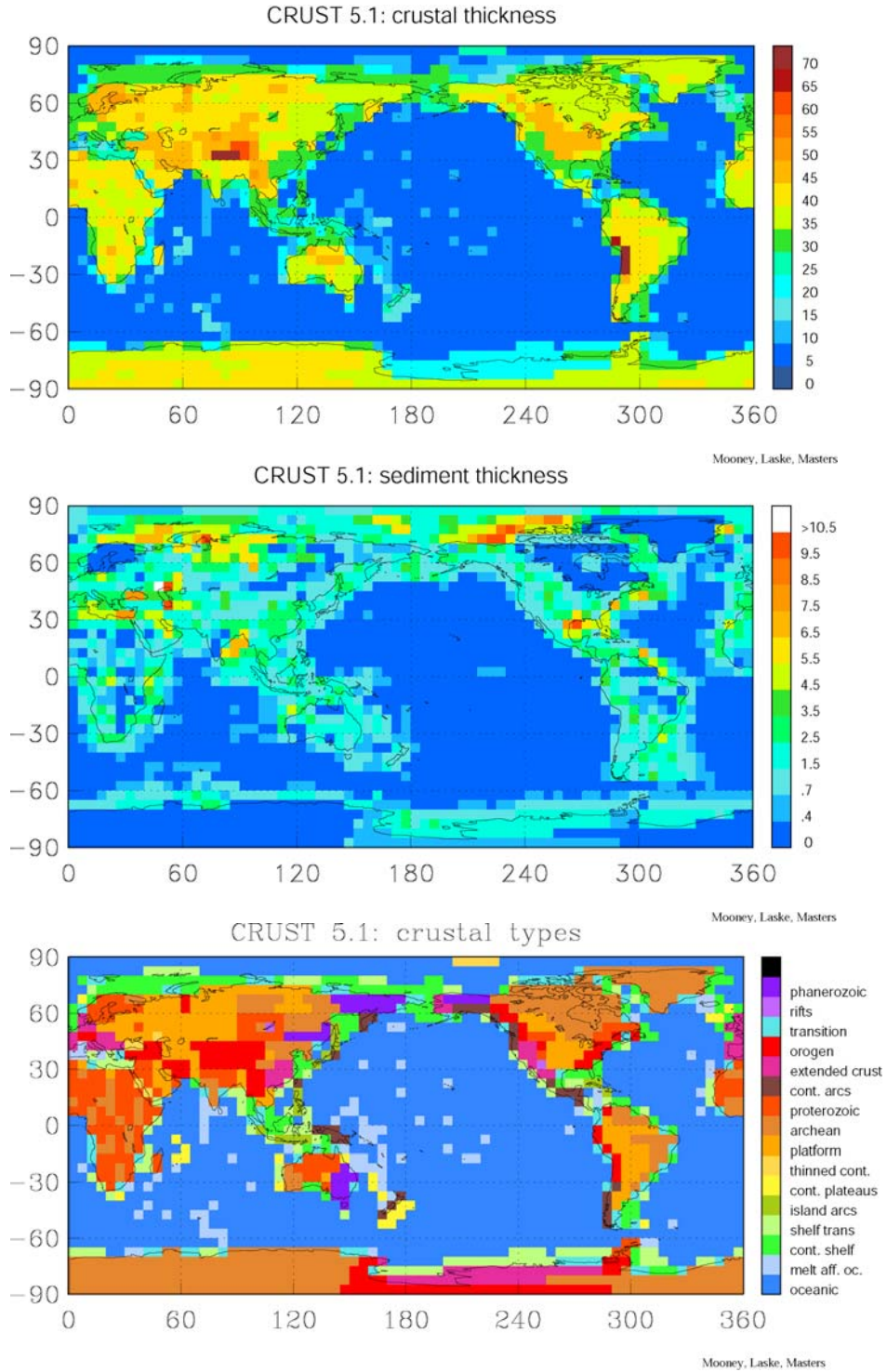


- Above is an example of non-uniqueness. Two models with different Moho depths both fit the same data.
- We now know that the crust is composed of lighter material, formed over geological time through a process of differentiation and fractionation.



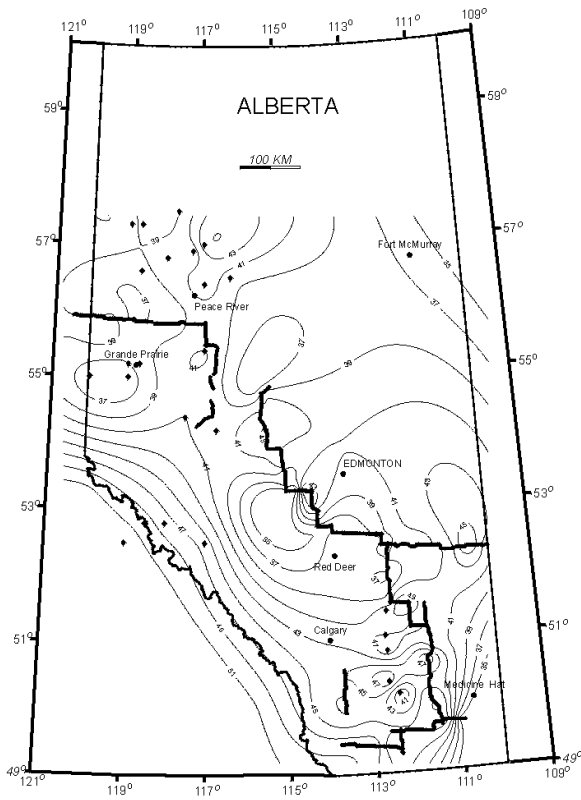
- Debate about rate of growth of continental crust over geological time (see Fowler 10-30).

- Continental crust has average thickness of 35 km, $v_p = 6.5$ km/s but very significant variations.



From : <http://mahi.ucsd.edu/Gabi/crust.html>. Also see Mooney *et al.*, 1998.

- crustal thickness in Alberta



BOUZIDI ET AL., FIGURE 8

Bouzidi *et al.*, (2002)

References

- Bouzidi, Y., D. R. Schmitt, R. Burwash, E. Kanasewich, Depth migration of deep seismic reflection profiles: crustal thickness variations in Alberta, *Can. J. Earth Sciences*, **39**, 331-350, 2002.
- Mooney, W.D., G. Laske and G. Masters, CRUST 5.1: A global crustal model at 5°x5°. *J. Geophys. Res.*, 103, 727-747, 1998
- Wilson, D.S., et al., Drilling to Gabbro in intact ocean crust, *Science*, 312, 1016-1020, 2006.