Lecture 2: Sea-floor depth, age, and heat flow

- Why do we have ocean basins?
- Mid ocean ridges and the topography of the sea-floor
- Heat transport in the Earth

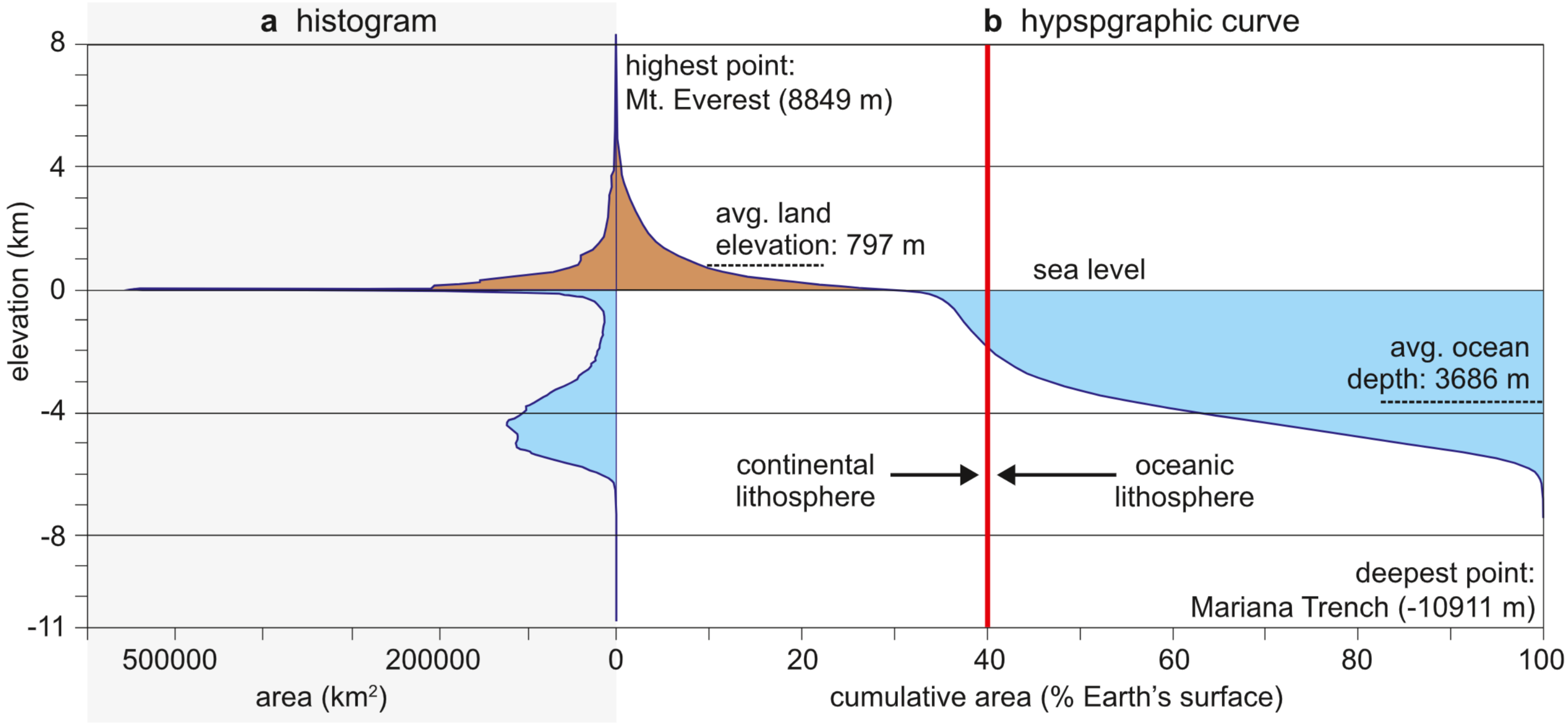
We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

What are ocean basins?

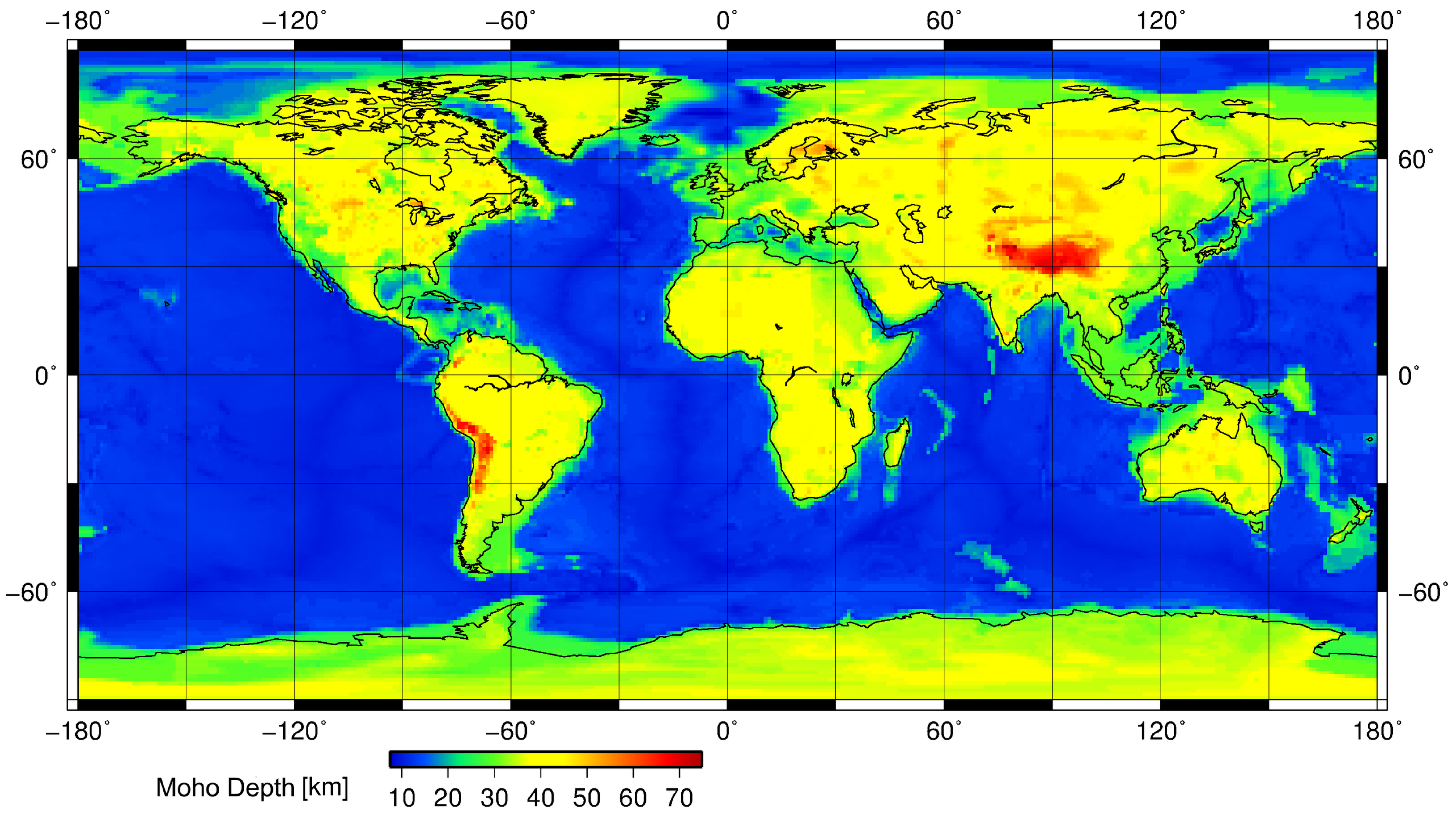
"We can only sense that in the deep and turbulent recesses of the sea are hidden mysteries far greater than any we have solved."

-Rachel Carson, *The Sea Around Us*, 1957

What are ocean basins?



Mohorovičić discontinuity



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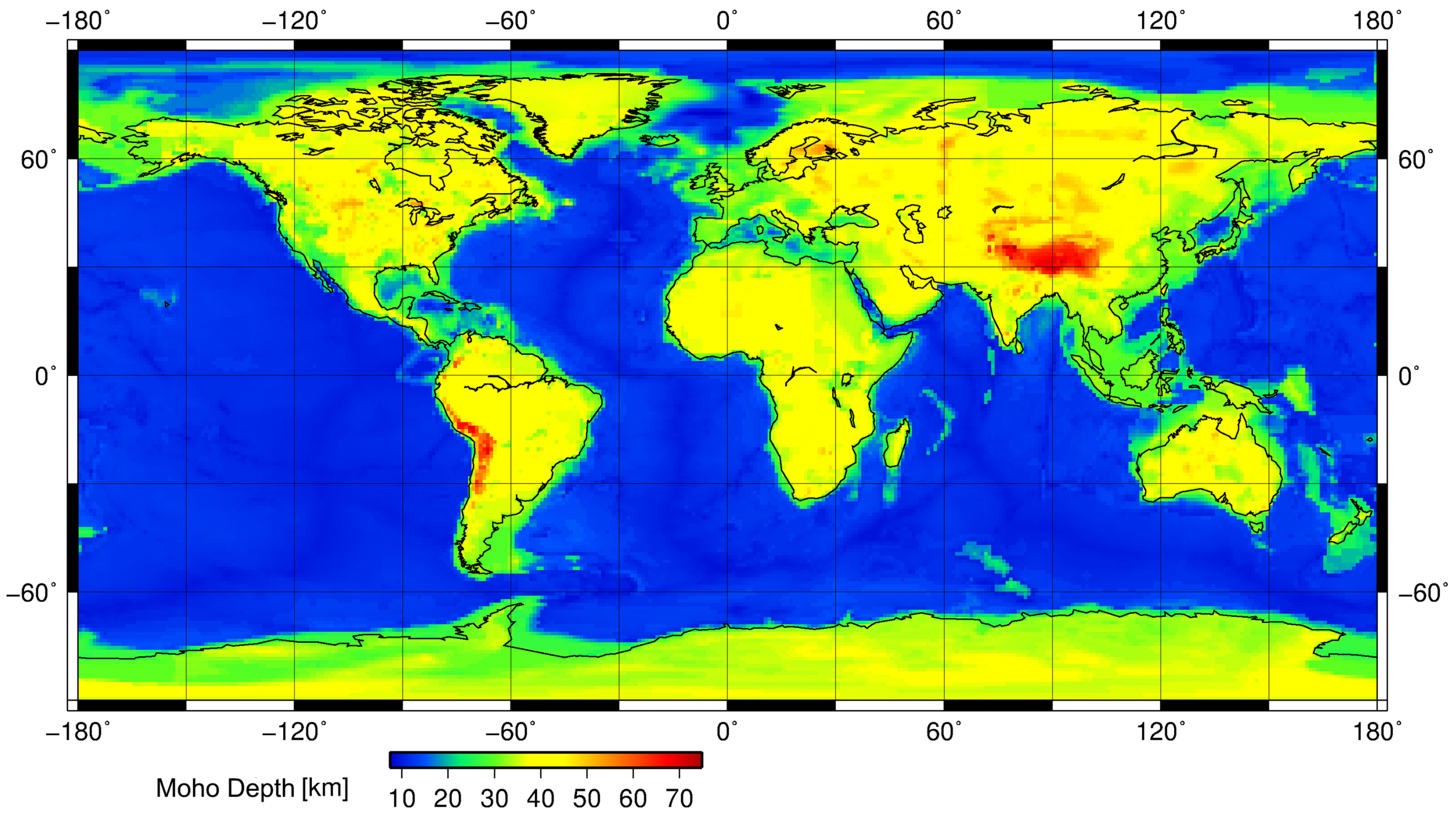

What are the differences between lithosphere and asthenosphere and crust and mantle?

Mohorovičić discontinuity

"Seismic evidence shows that the so-called crustal thickness-depth to the M discontinuity-is 6 km under oceans and 34 km under continents on the average."

-Harry Hess, *History of Ocean Basins*, 1962

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How can we test this assumption?

Testing isostatic equilibrium

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- Continental crust:
  - Mean elevation: 797 m
  - Mean thickness: 34 km
  - Andesite with density: 2.8 g/cm^3
- Oceanic crust:
  - Mean elevation: -3686 m
  - Mean thickness: 6 km
  - Basalt with density: 2.9 g/cm^3
- Density of water: 1 g/cm^3

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What is the density of the mantle in g/cm^3?

Testing isostatic equilibrium

The calculation is simplest if we assume compensation depth is the base of the continental crust (instead of the 40 km hypothetical posed by Hess). You should get **3.46 g/cm^3** (density of peridotite: 3.1–3.4 g/cm^3) using the following mass balance:

$$\Delta \mathrm{H_{cc}} \rho_{\mathrm{cc}} = \Delta \mathrm{H_w} \rho_{\mathrm{w}} + \Delta \mathrm{H_{oc}} \rho_{\mathrm{oc}} + \Delta \mathrm{H_m} \rho_{\mathrm{m}}$$

$$\Delta \mathrm{H_{cc}} \rho_{\mathrm{cc}} - \Delta \mathrm{H_w} \rho_{\mathrm{w}} - \Delta \mathrm{H_{oc}} \rho_{\mathrm{oc}} = \Delta \mathrm{H_m} \rho_{\mathrm{m}}$$

$$\frac{\Delta \mathrm{H_{cc}} \rho_{\mathrm{cc}} - \Delta \mathrm{H_w} \rho_{\mathrm{w}} - \Delta \mathrm{H_{oc}} \rho_{\mathrm{oc}}}{\Delta \mathrm{H_m}} = \rho_{\mathrm{m}}$$

$$\Delta \mathrm{H_m} = \Delta \mathrm{H_{cc}} - \Delta \mathrm{H_{oc}} - \mathrm{E_{cc}} - \mathrm{E_{oc}}$$

where ΔH is thickness, E is elevation, ρ is density, and the subscripts w, cc, oc, and m correspond to the water in the ocean, the continental crust, the oceanic crust, and the mantle, respectively.

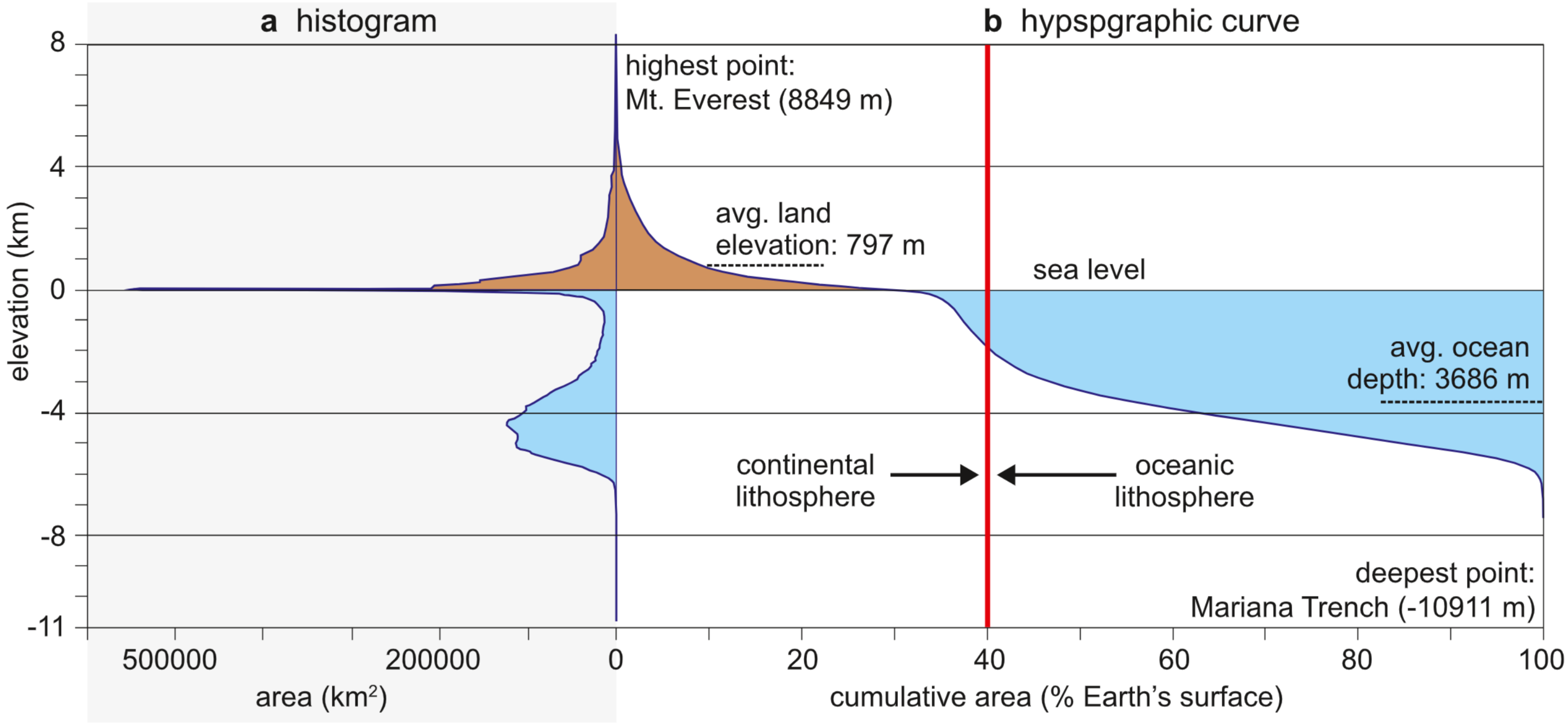
In [20]:

```python
crust_thickness = 34
crust_elevation = 0.797
crust_density = 2.8  # kg/m^3
ocean_thickness = 6
ocean_elevation = -3.686
ocean_density = 2.9  # kg/m^3
water_density = 1
water_thickness = 3.686
mantle_root = crust_thickness - ocean_thickness - (crust_elevation - ocean_elevation)

# crust_thickness*crust_density = water_thickness*water_density + ocean_thickness*ocean_density +
#                                                                            mantle_density*mantle_root
mantle_density = (
    water_thickness * water_density
    + crust_thickness * crust_density
    - ocean_thickness * ocean_density
) / mantle_root
mantle_density
```

Out[20]: 3.4649827784156138

The topography of the sea-floor



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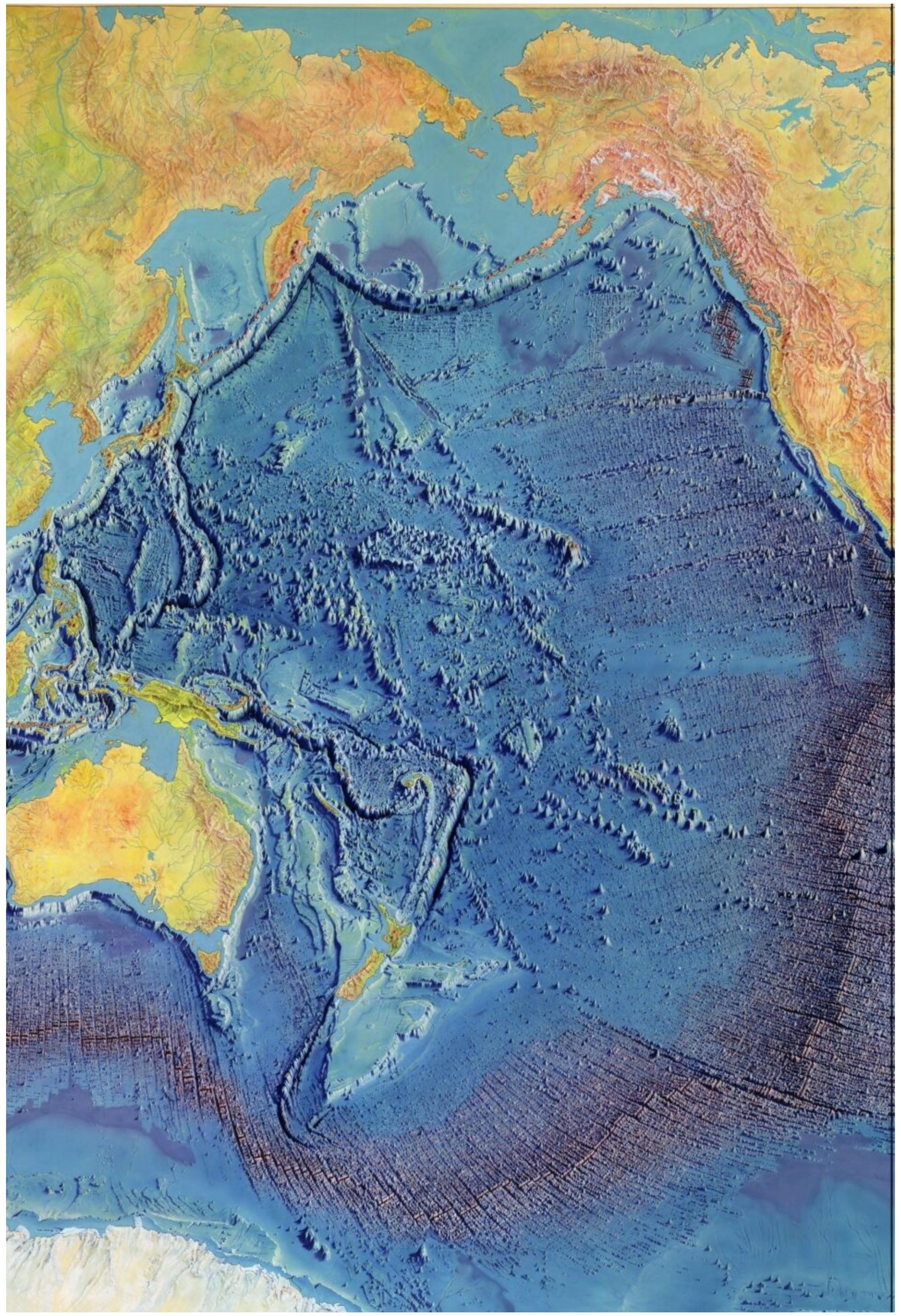

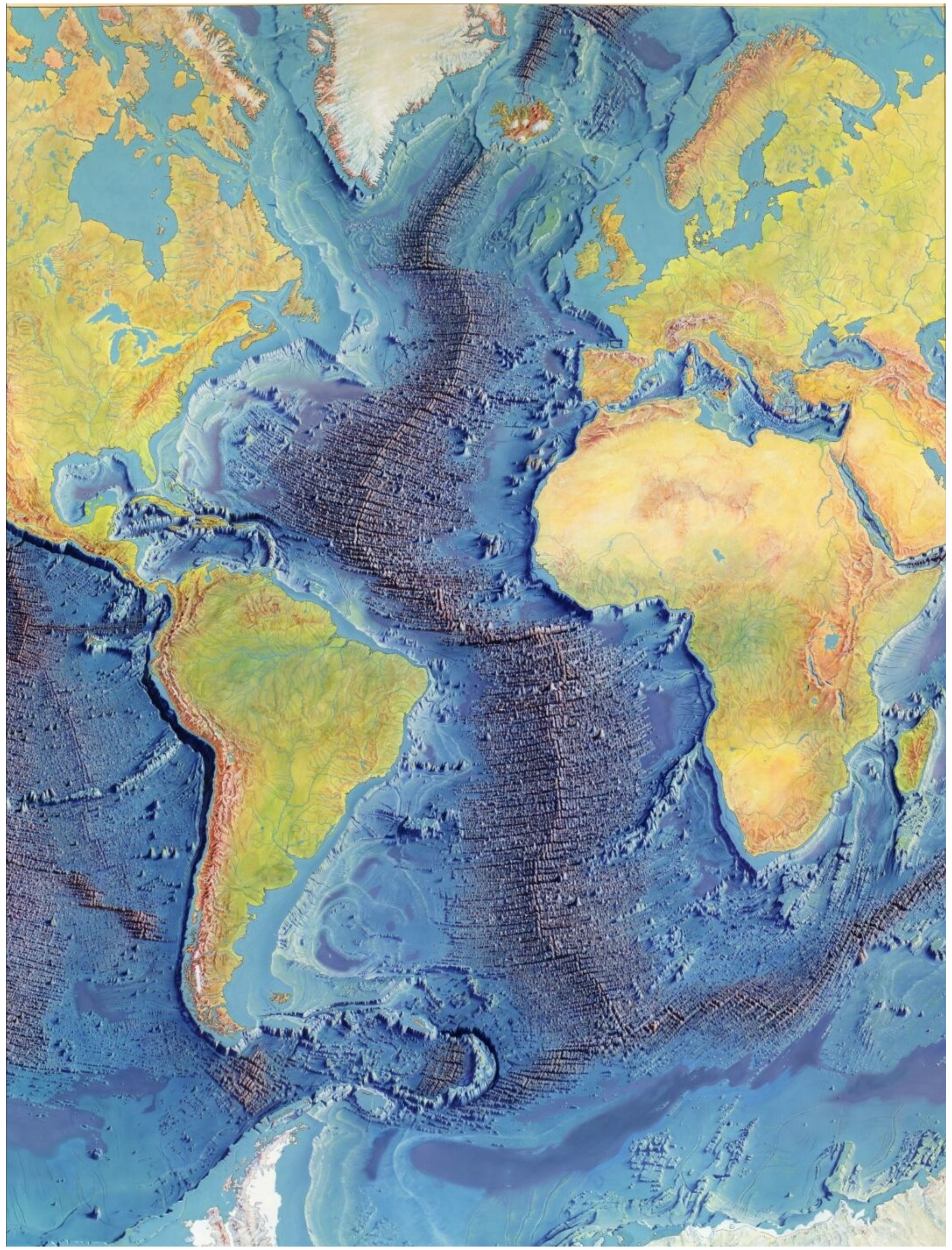

The topography of the sea-floor

Consider at least two ways that the topography of the sea-floor (mid-ocean ridges and the increase in depth away from ridges) can be in isostatic equilibrium. Draw a sketch for both.

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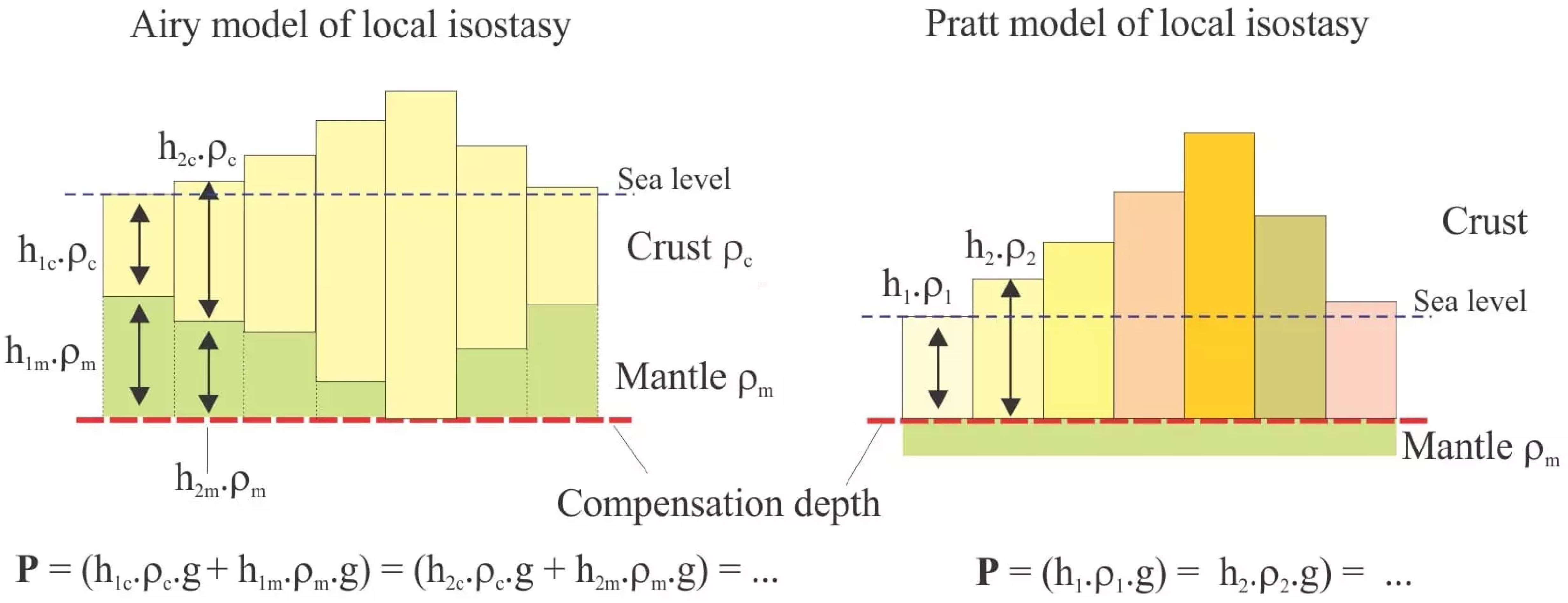


Which model is better at explaining sea-floor topography? Why?

The topography of the sea-floor

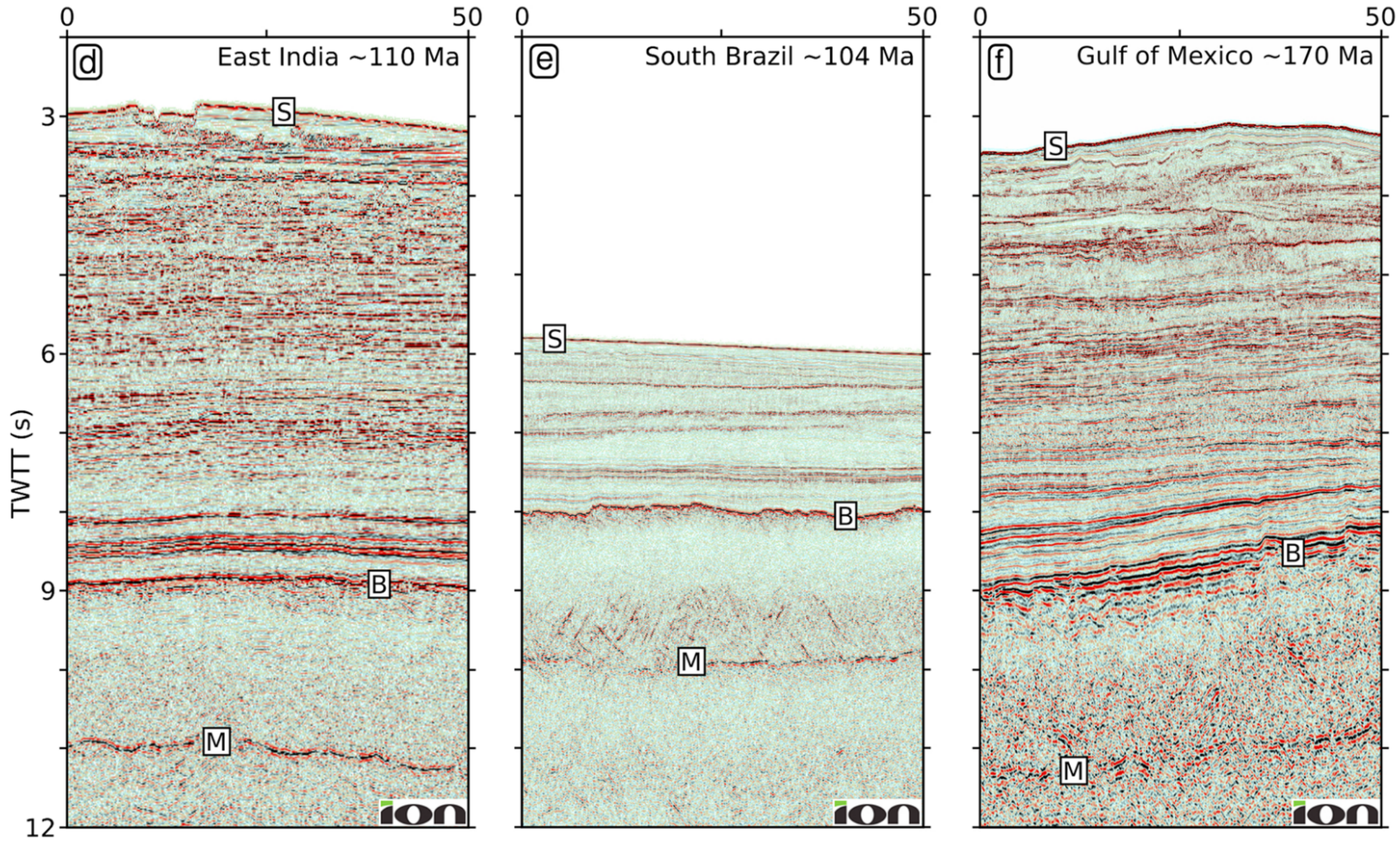
"Nevertheless, mantle convection is considered a radical hypothesis not widely accepted by geologists and geophysicists. If it were accepted, a rather reasonable story could be constructed to describe the evolution of ocean basins and the waters within them. Whole realms of previously unrelated facts fall into a regular pattern, which suggests that close approach to satisfactory theory is being attained."

-Harry Hess, *History of Ocean Basins*, 1962

What observations supported this radical hypothesis?

The lithosphere

We can image the crust pretty well, but not the base of the lithosphere



Temperature profile of Earth's lithosphere and upper asthenosphere (sketch first)

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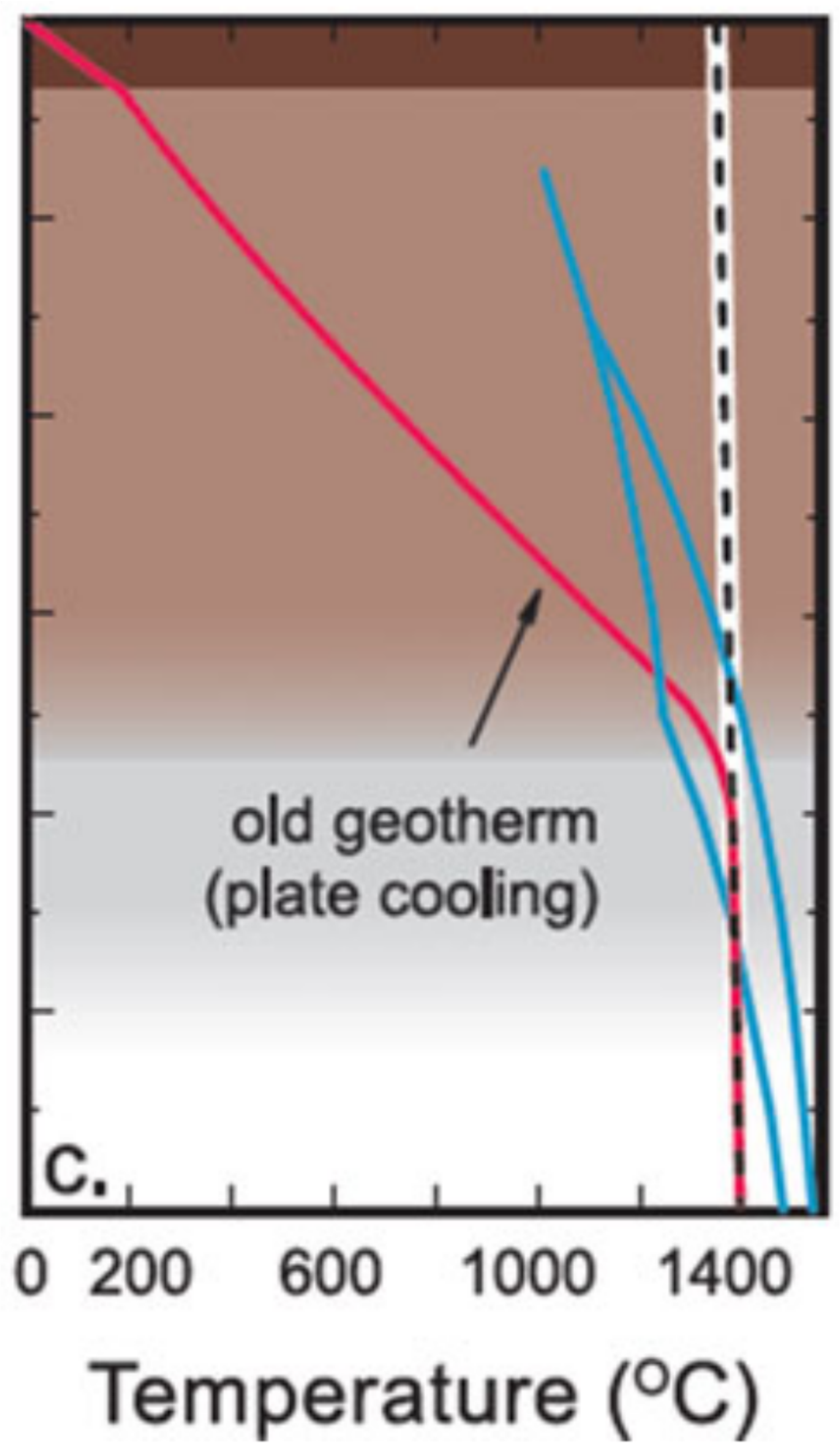

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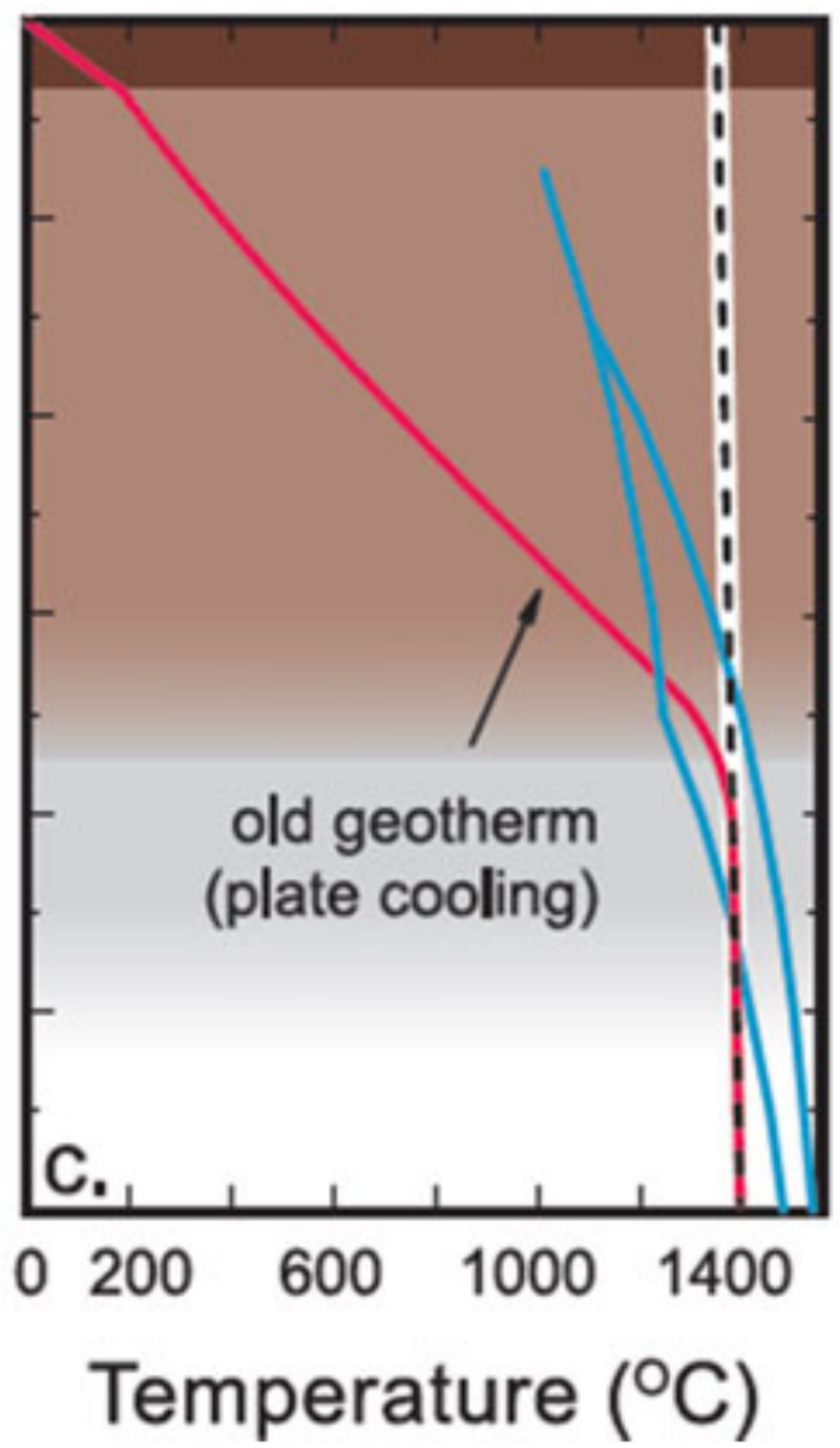

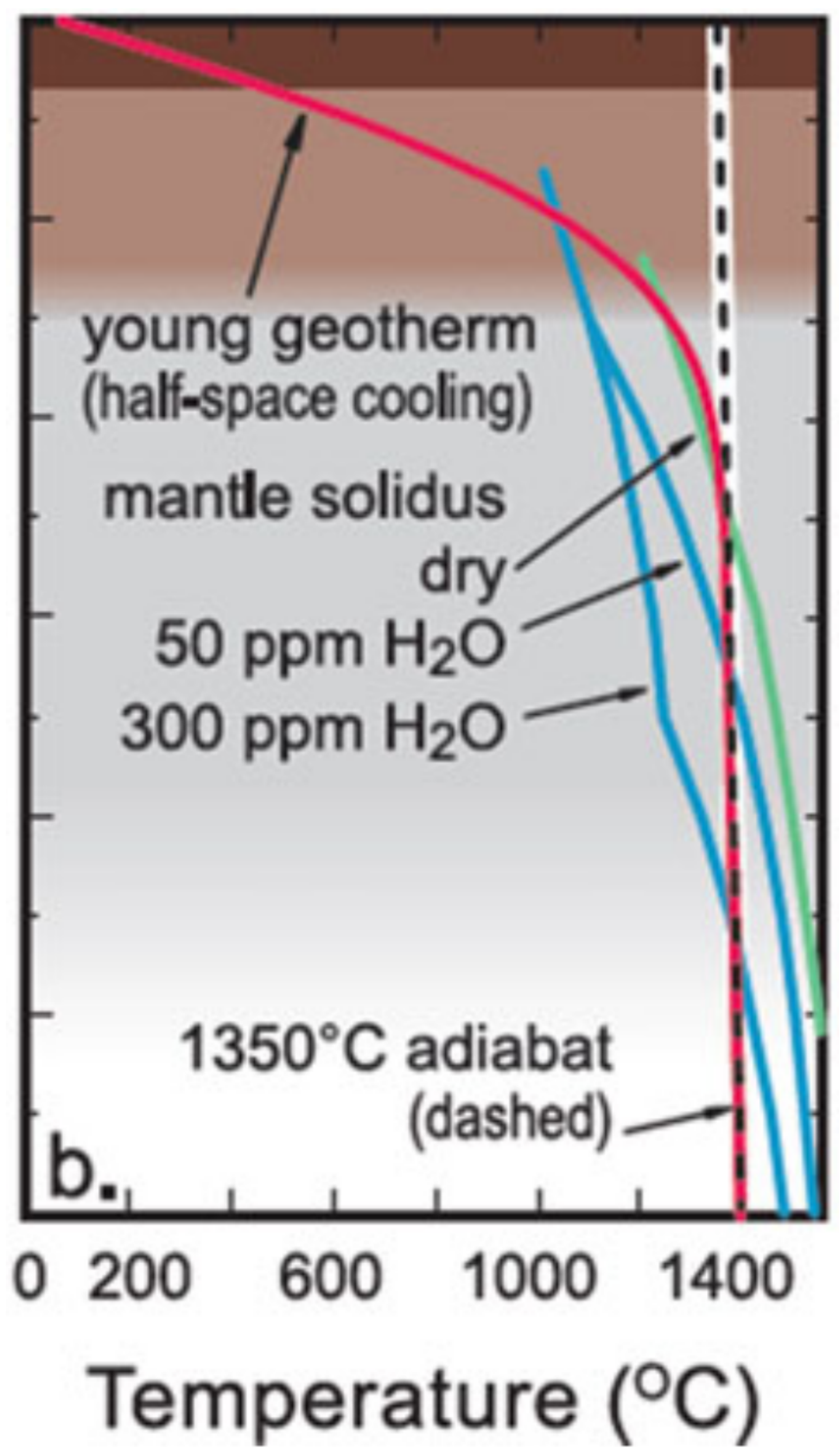

Heat flux (Fourier's law)

The differential form of Fourier's law of thermal conduction shows that the local heat flux density, q, is equal to the product of thermal conductivity, k, and the negative local temperature gradient, $\partial T / \partial x$. The heat flux density is the amount of energy that flows through a unit area per unit time.

$$q = -k \frac{\partial T}{\partial x}$$

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The diffusion equation:

$$\frac{\partial T}{\partial t} = \frac{\partial q}{\partial x}$$

$$\frac{\partial T}{\partial t} = -k\frac{\partial^2 T}{\partial x^2}$$

Heat flux (Fourier's law)

- Using your intuition of diffusion, draw some sketches showing:
  - Temperature profile of asthenosphere (1400 ˚C) instantly brought to the surface (0 ˚C)
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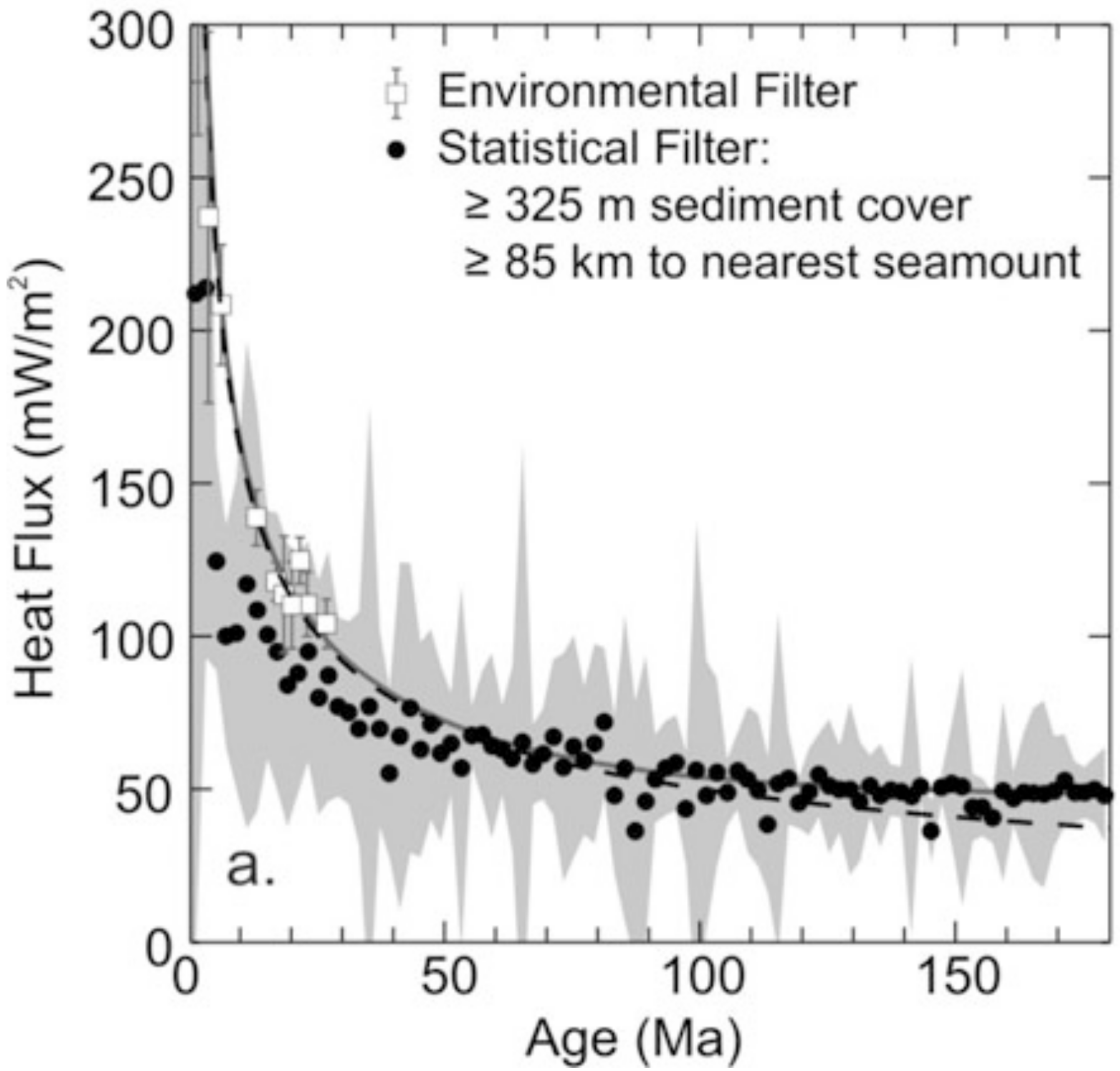
How does heat flux, q, change at the surface in each instance?

- Draw a sketch of a mid ocean ridge, annotating the crust, the lithosphere-asthenosphere boundary, and a few isotherms (temperature contours)

Heat flux observations



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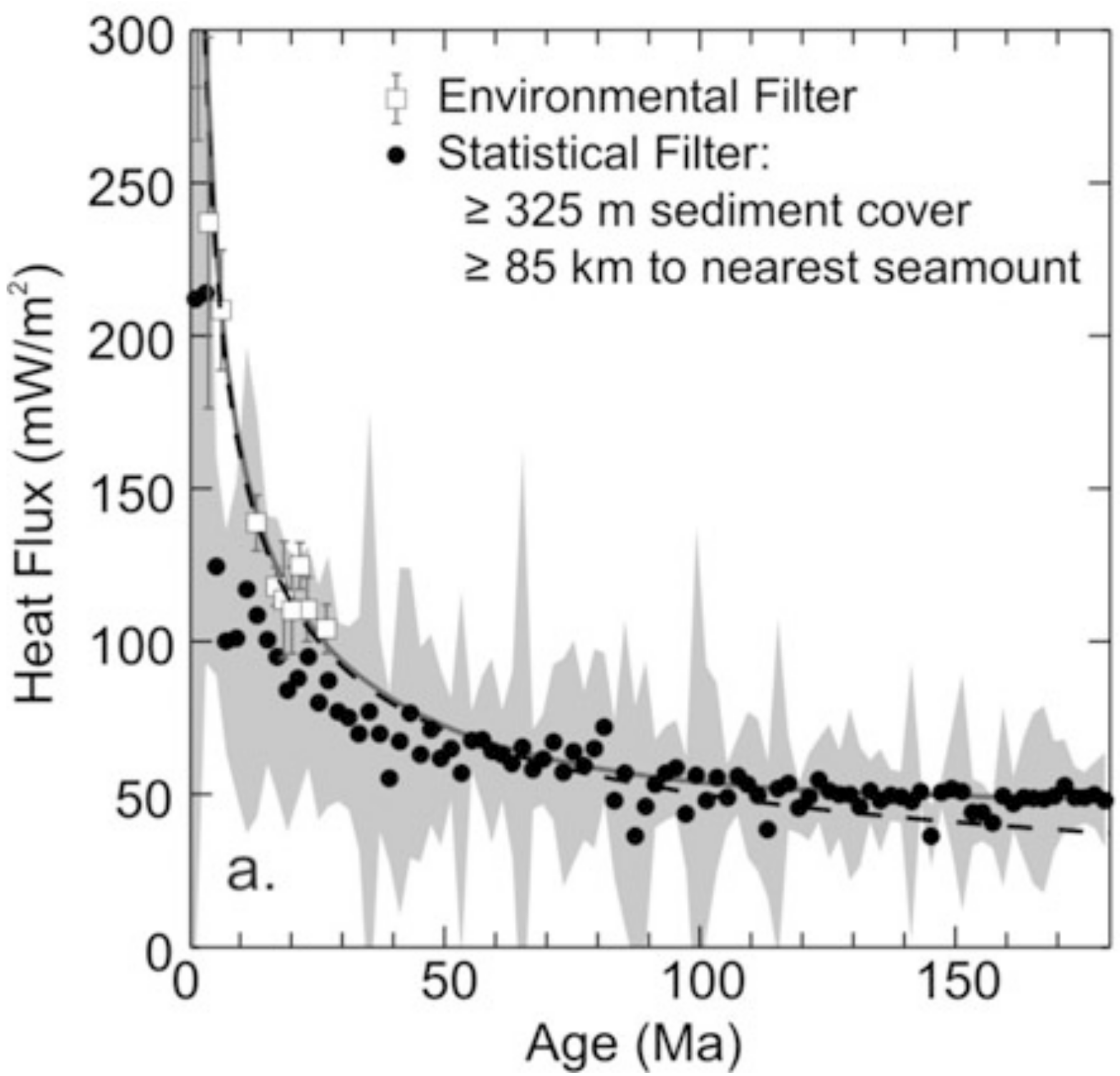
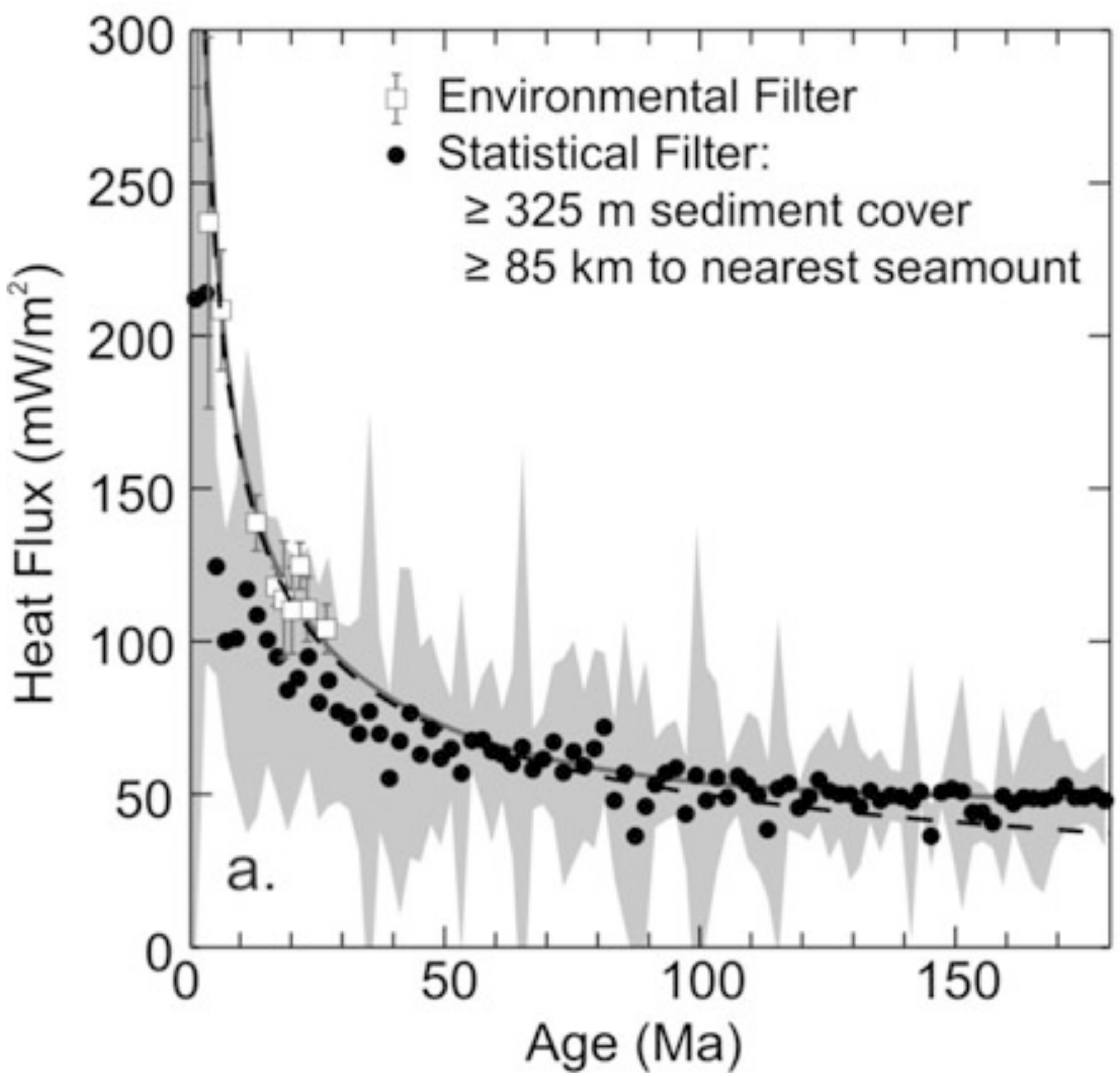


Dashed line represents a simple conductive cooling model. What patterns to the misfit do you see?

Heat flux observations



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Younger sea-floor has hydrothermal cooling (lower heat flux than expected). We'll take a closer look at the old sea-floor problem soon!

Boundary Layer Model (cooling of an infinite half-space)