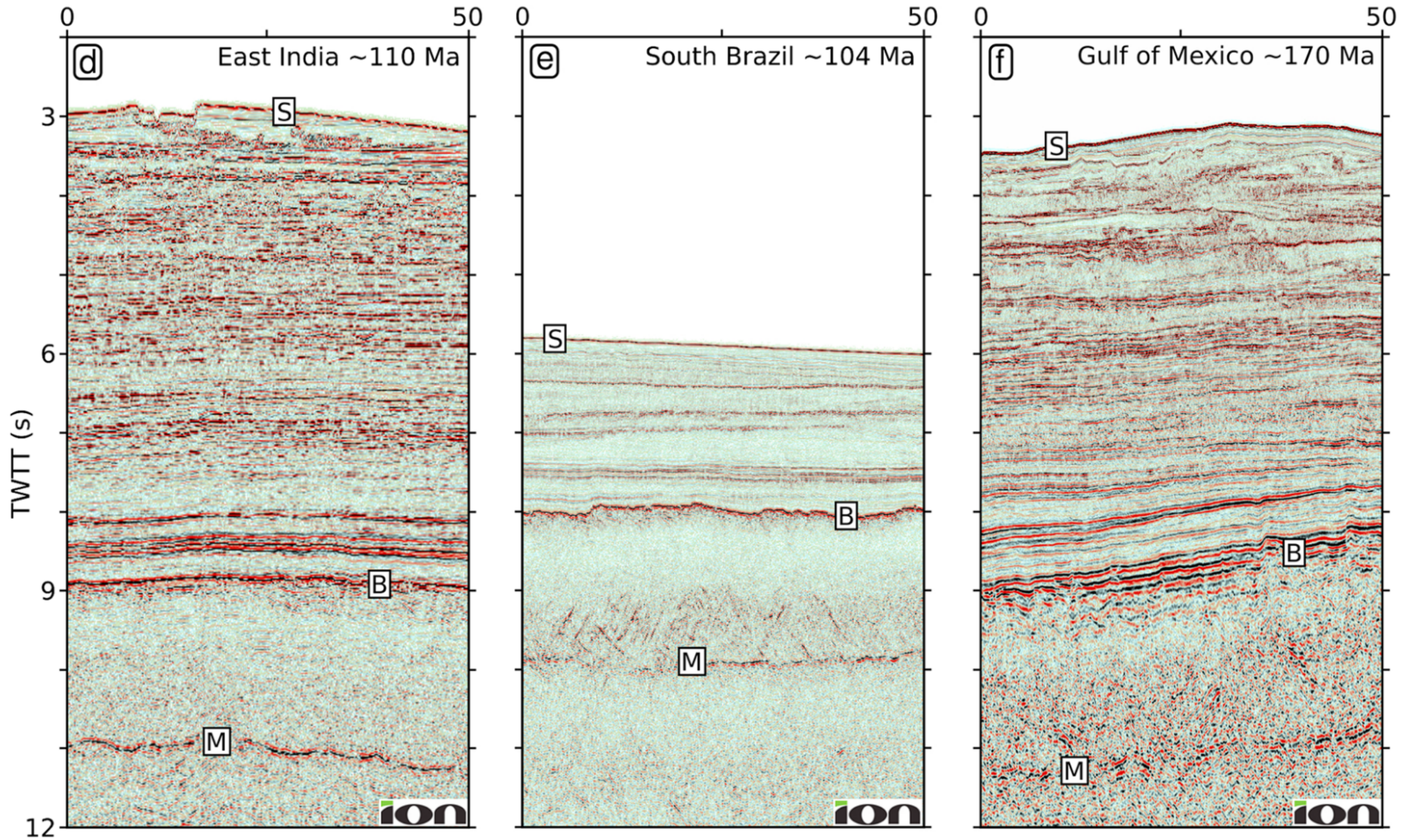
Lecture 3: Sea-floor depth, age, and heat flow

- Mid ocean ridges and the topography of the sea-floor
    - Heat transport in the Earth
    - Boundary layer model
    - Plate model
- How do we map the seafloor today?
    - Stochastic reheating model

We acknowledge and respect the ləkʷəŋən 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.

The lithosphere

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



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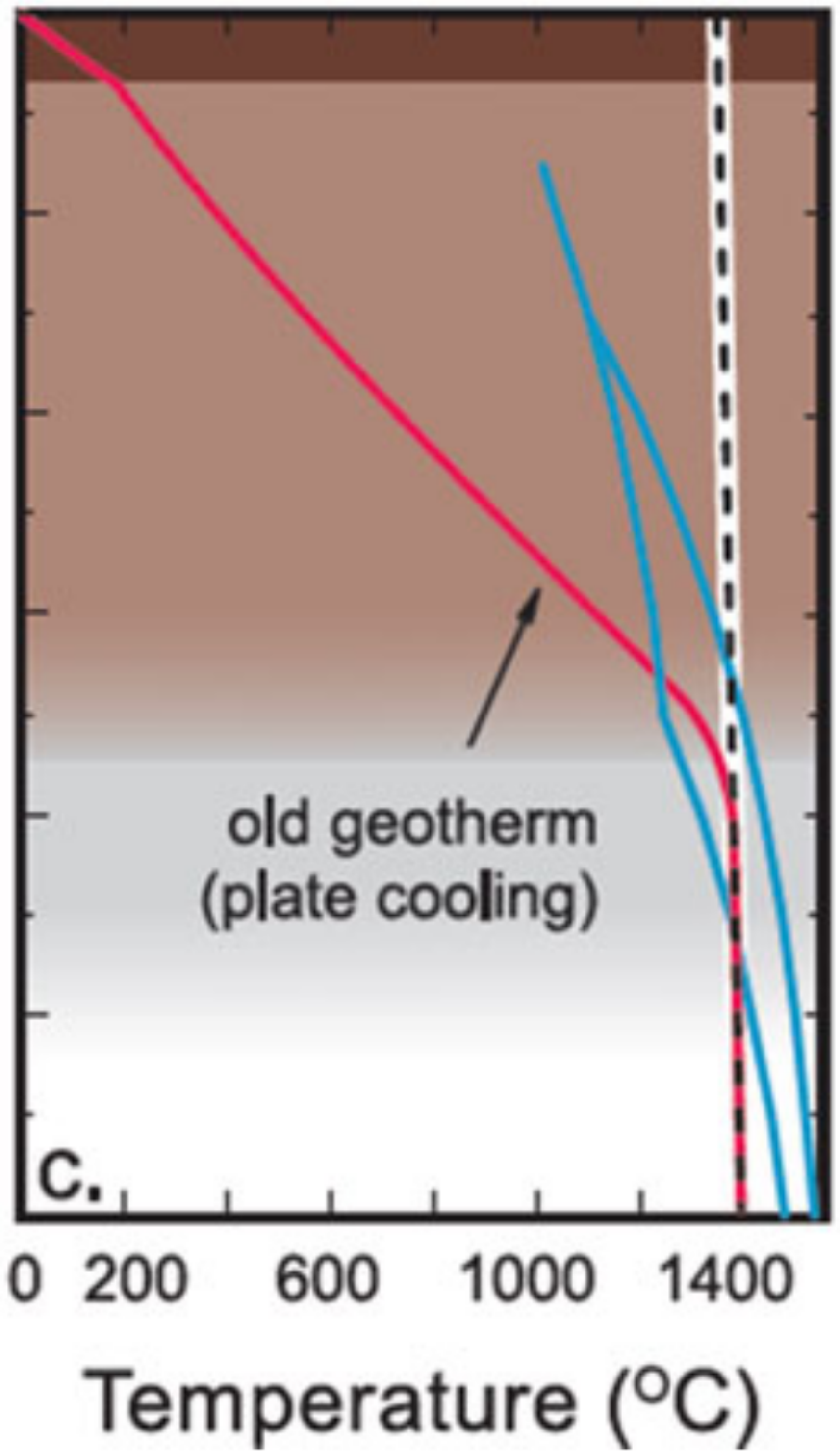

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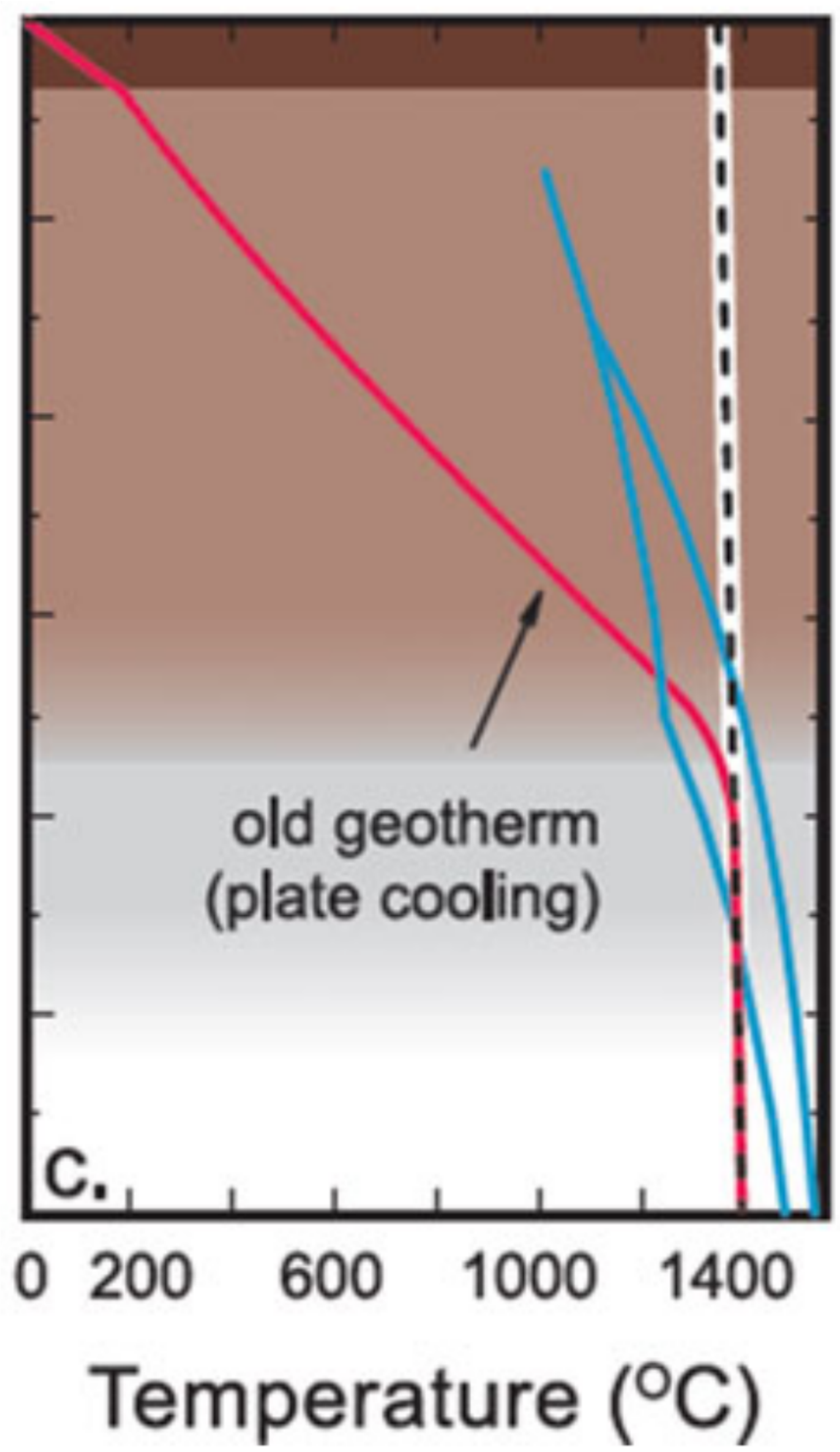

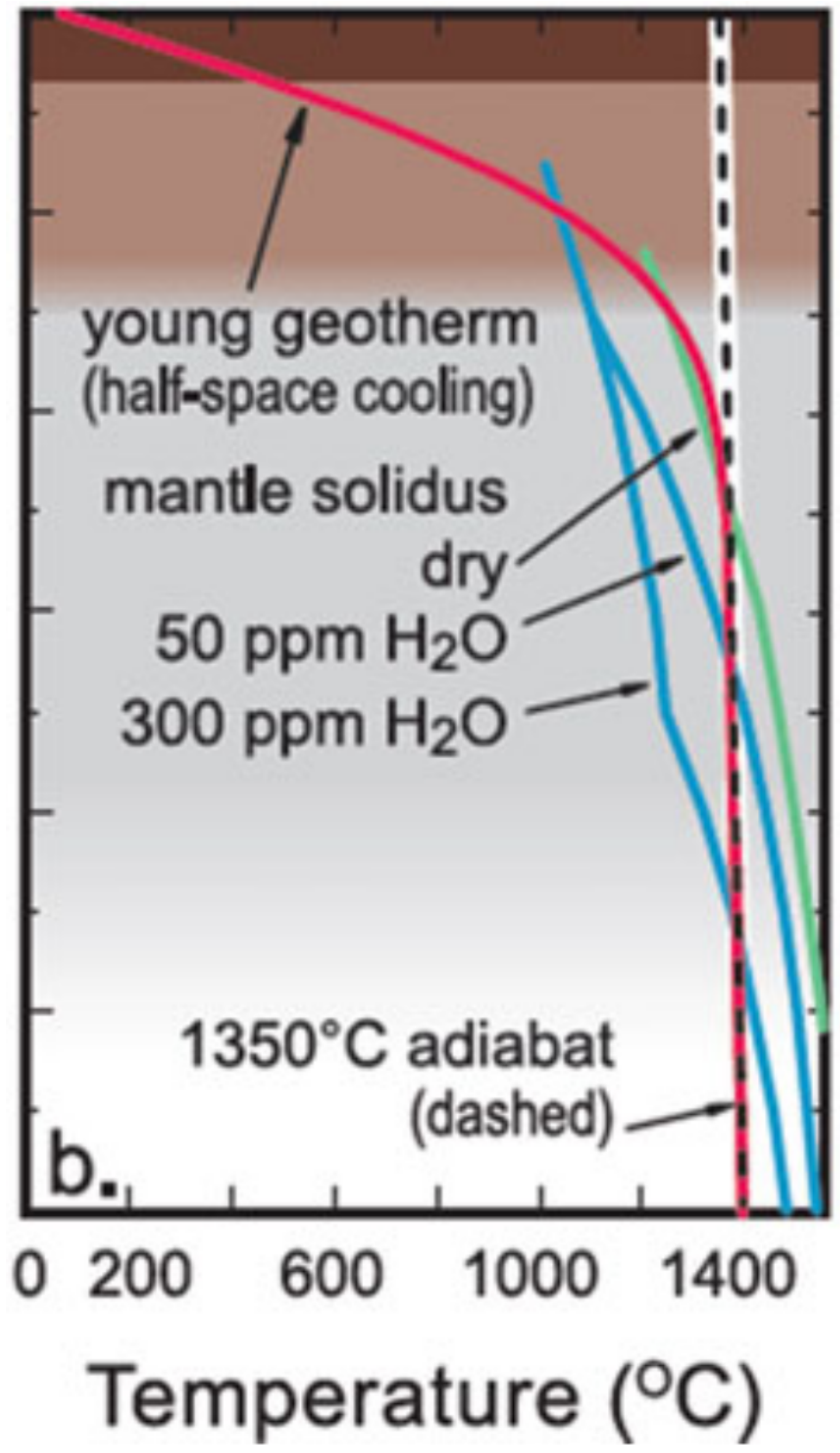

Heat flux (Fourier's law)

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.

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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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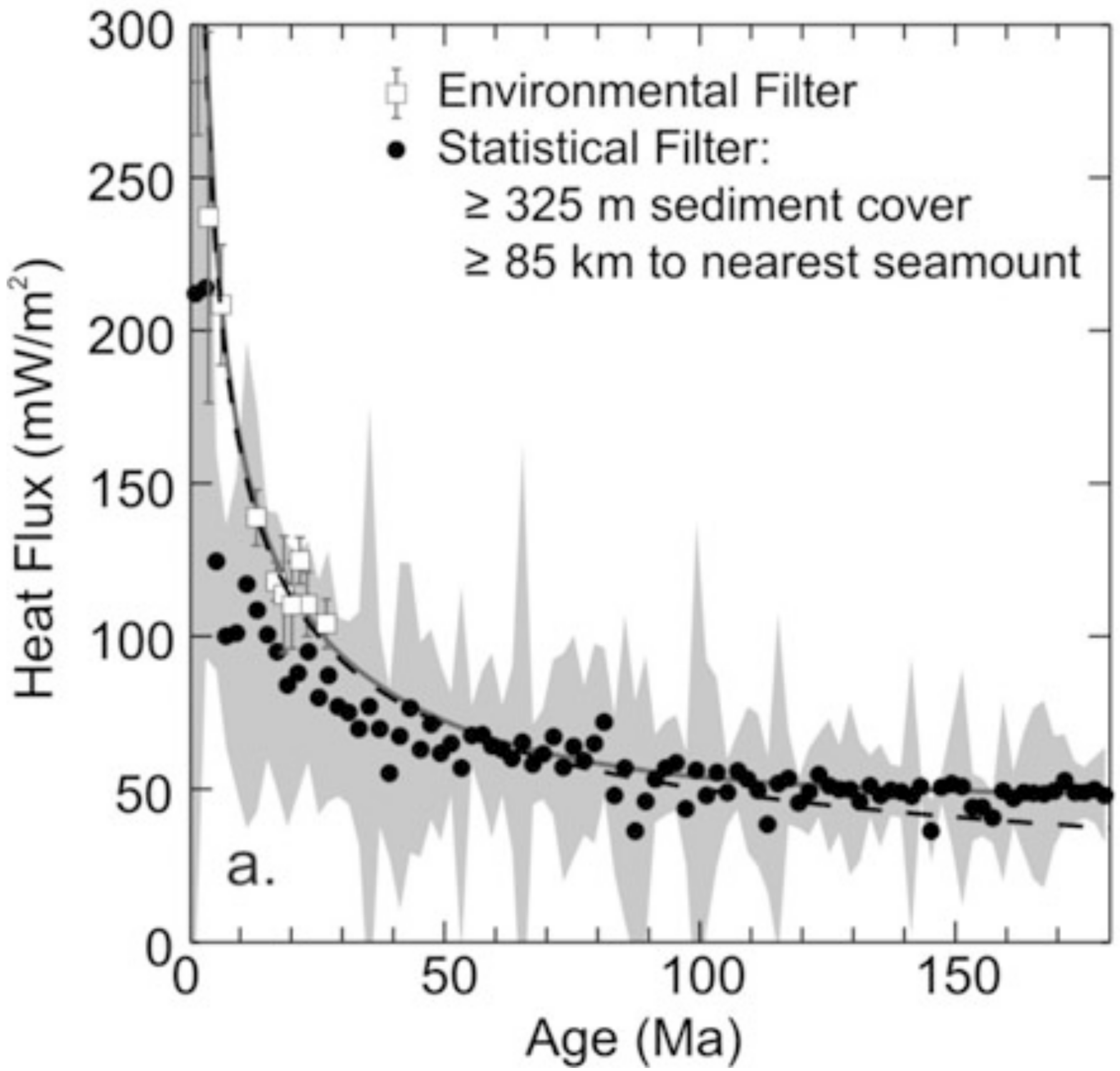
How does heat flux, q, change at the surface in each instance?

- 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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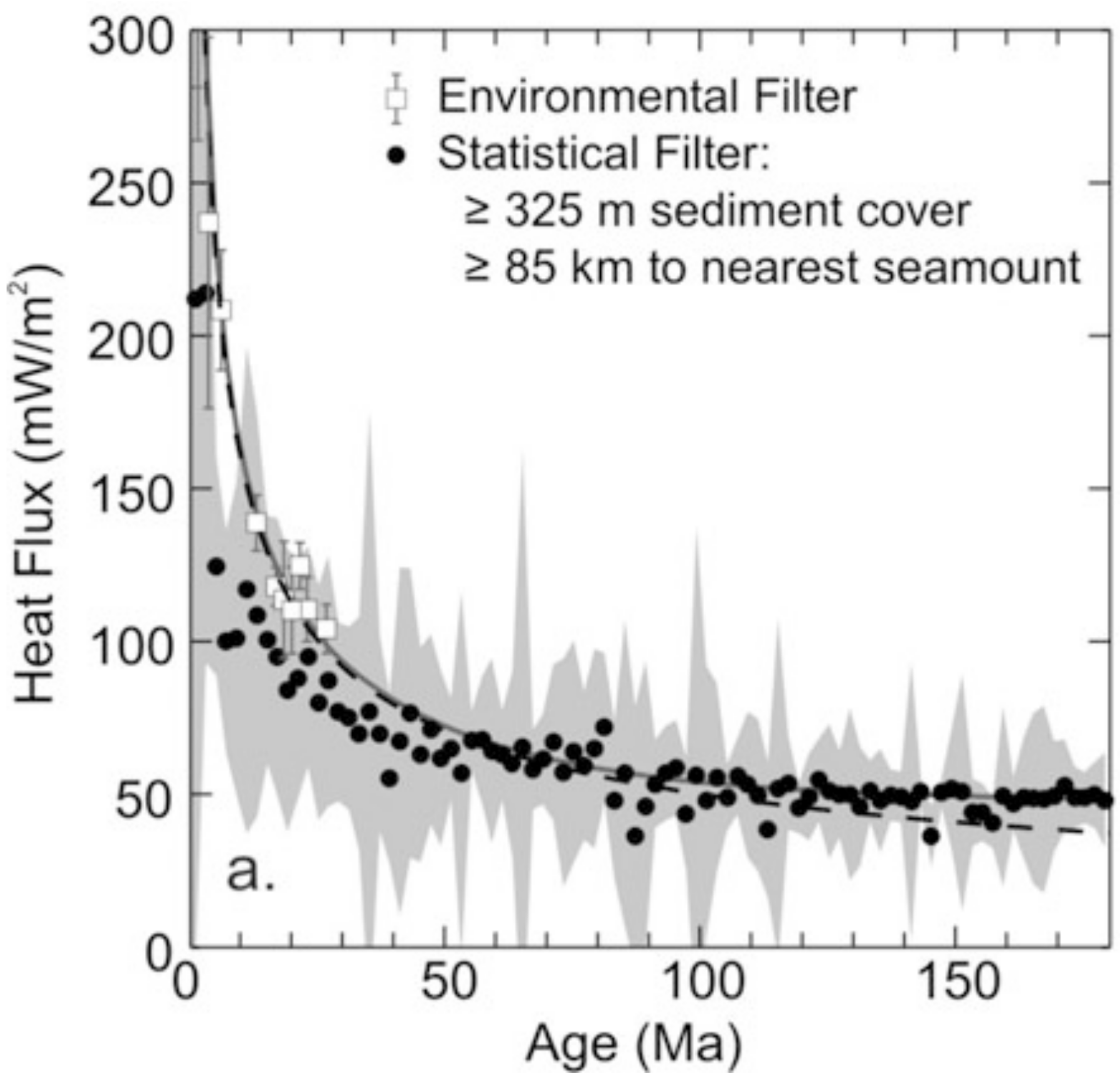

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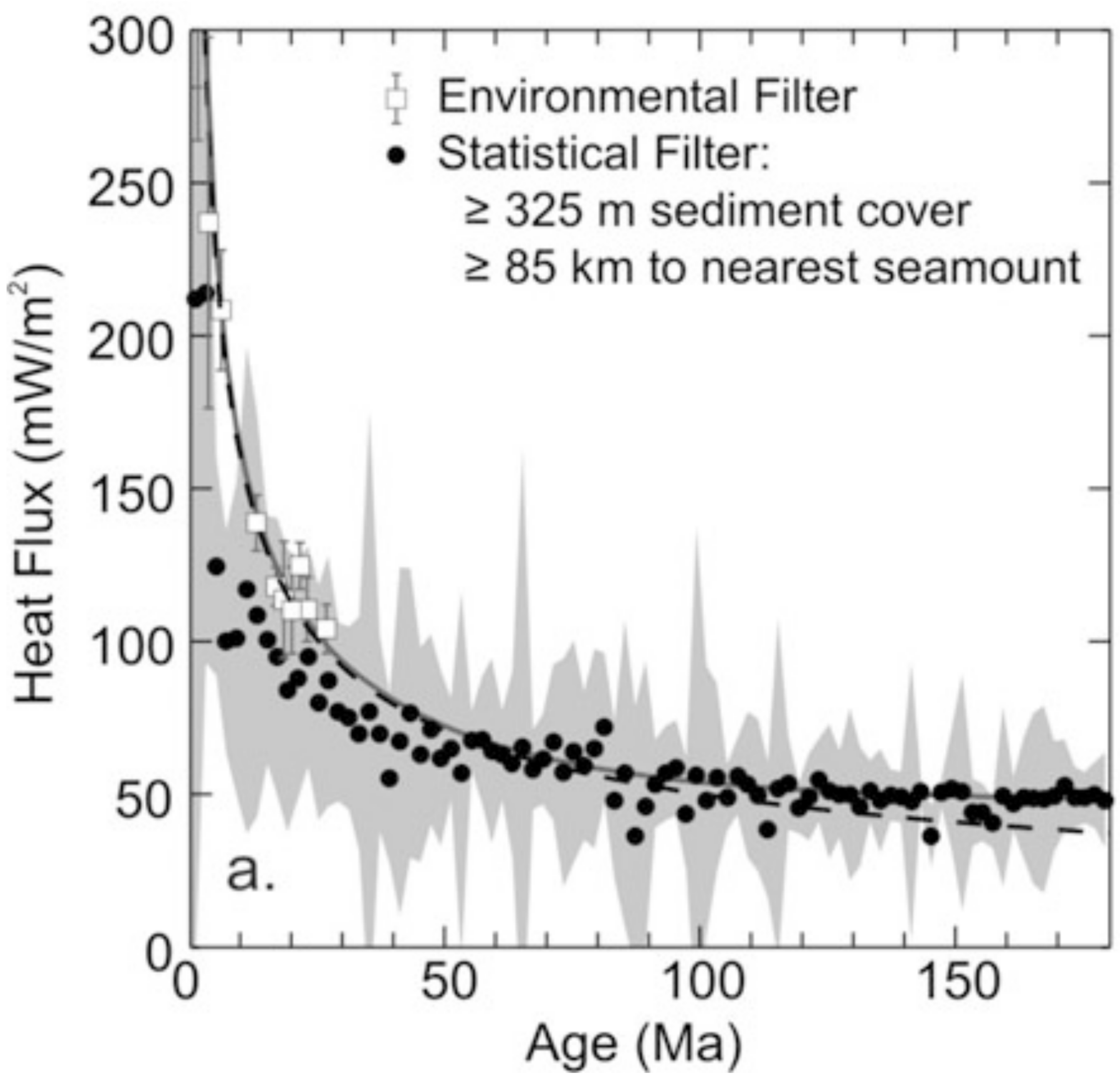

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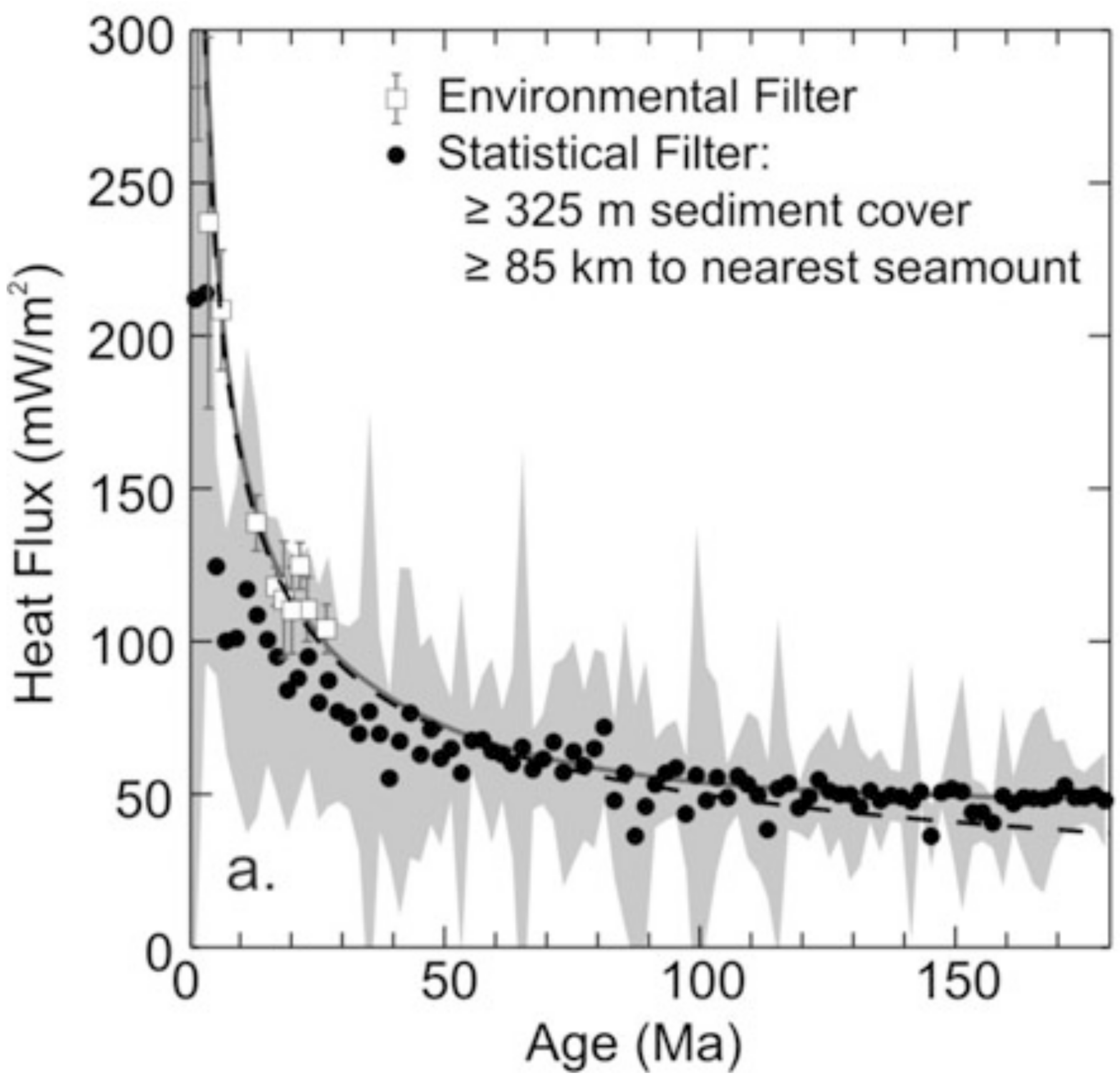

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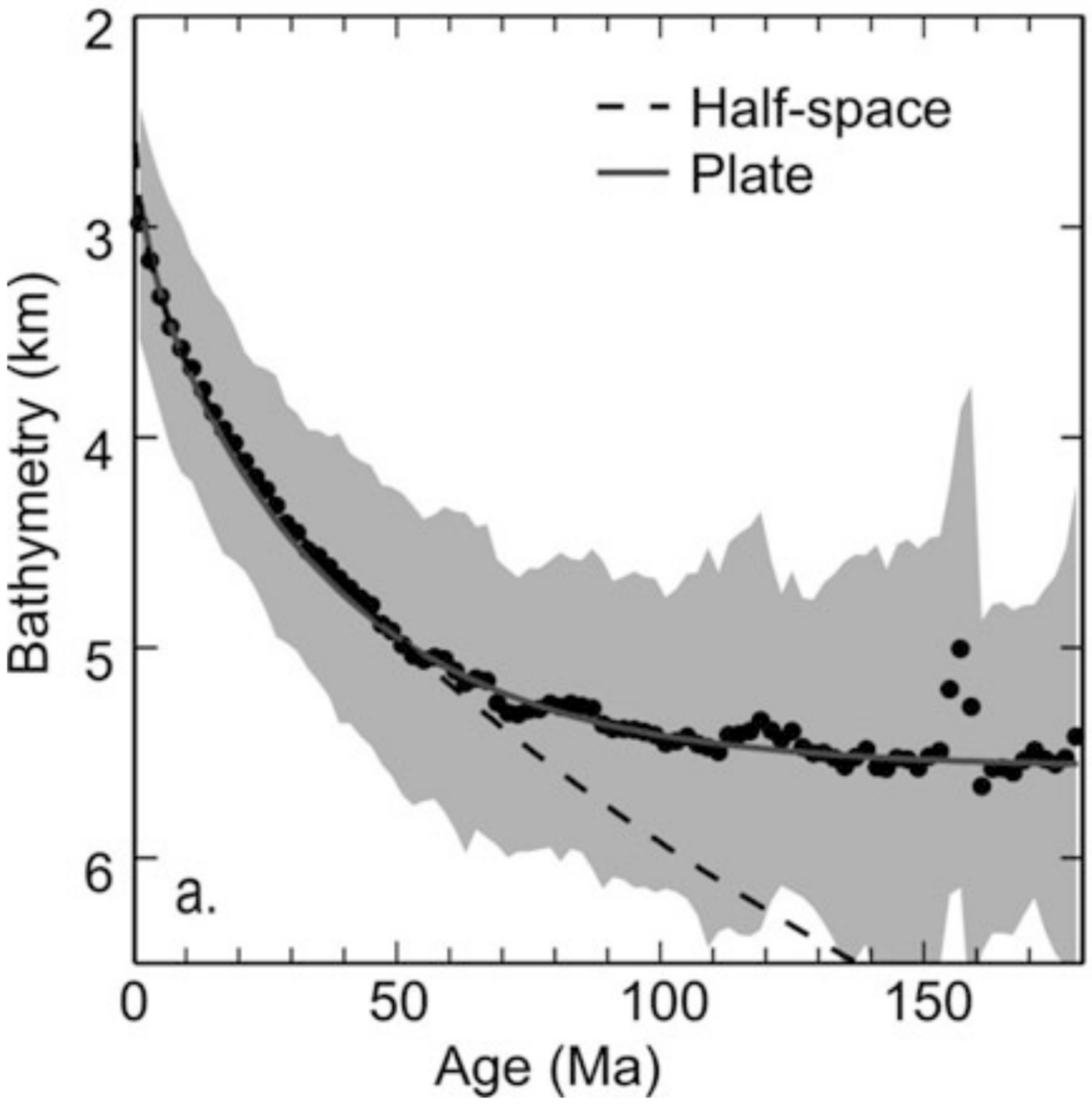
Under what conditions do you get a **steady state** solution to the **heat equation**? What does this solution look like? (draw a profile)

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



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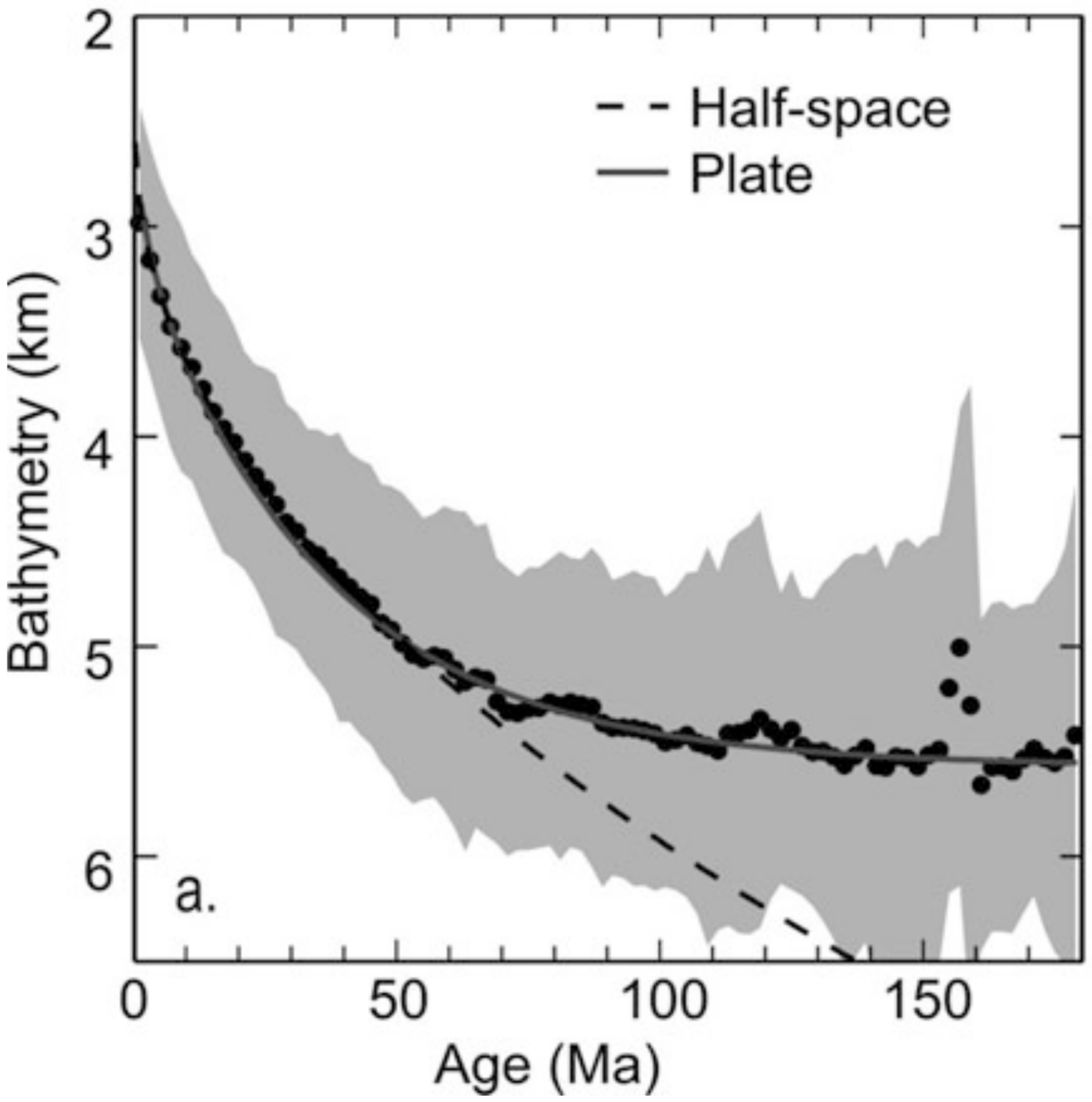

If the sea-floor gets deeper away from a mid-ocean ridge, is the lithosphere density high or lower than the asthenosphere?

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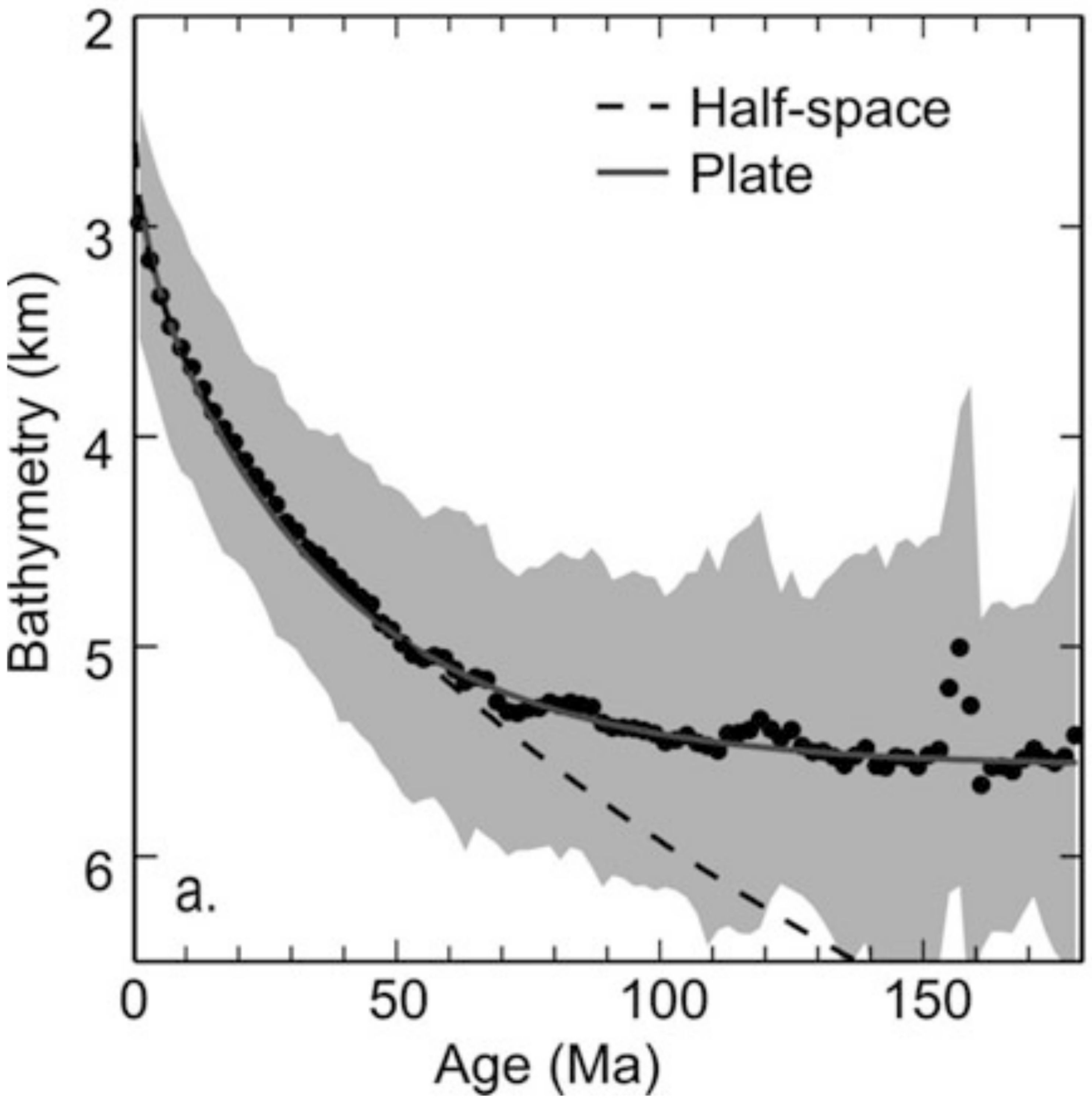

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- Calculate the thickness of the lithosphere
  - at 0 Ma (3 km bathymetry)
  - at 20 Ma (4 km bathymetry)
  - at 50 Ma (5 km bathymetry)
- Using the following densities:
  - Cool peridotite (lithosphere): 3400 kg/m^3
  - Hot peridotite (asthenosphere): 3300 kg/m^3
  - Water: 1000 kg/m^3

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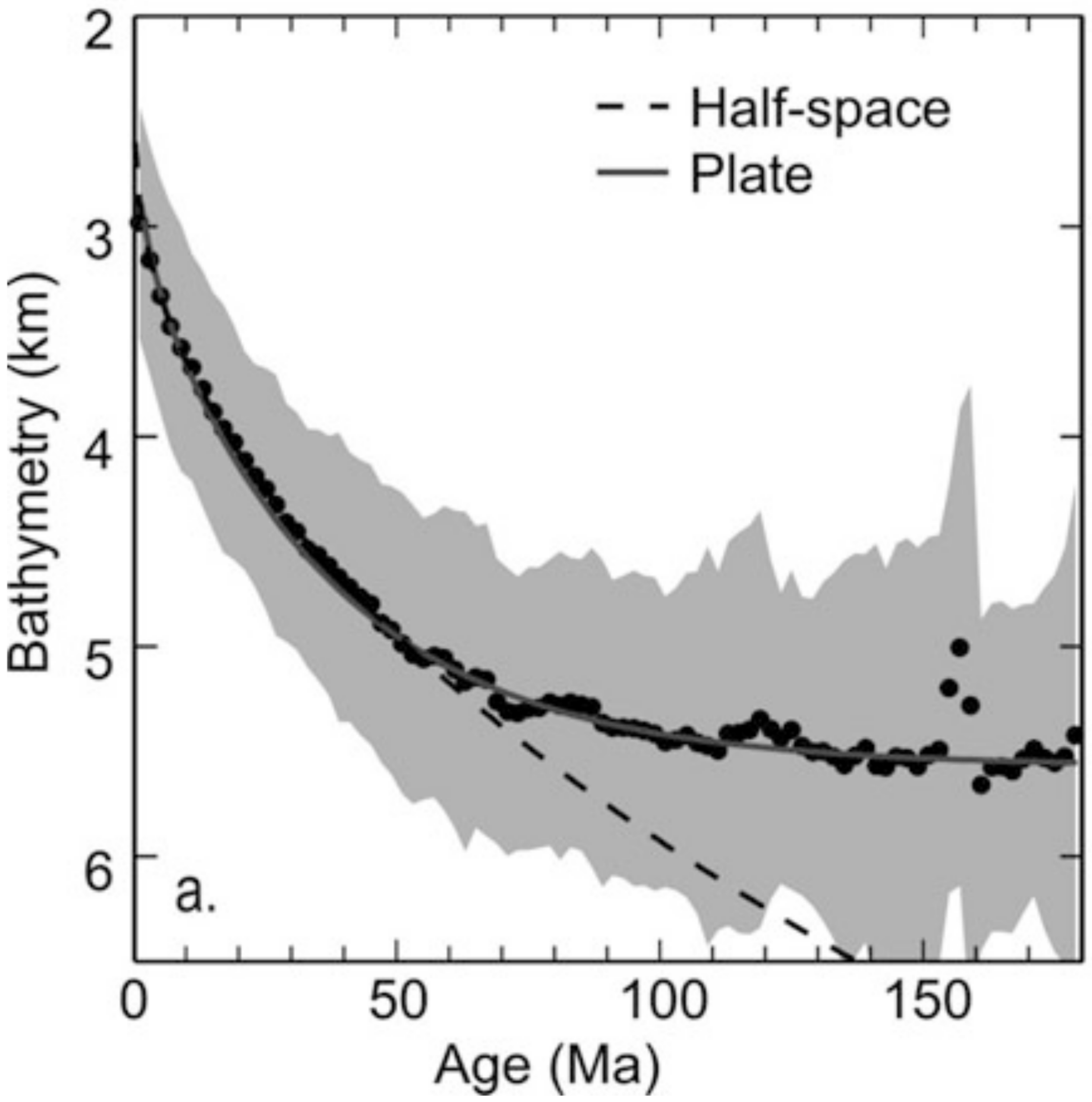

The dashed line is the predicted topography of the sea-floor using the diffusion equation and measured thermal conductivities of mantle material. Why do you think the model fails for older crust?

The denser lithosphere thickness stops increasing (maximum plate thickness). Why?

Plate model

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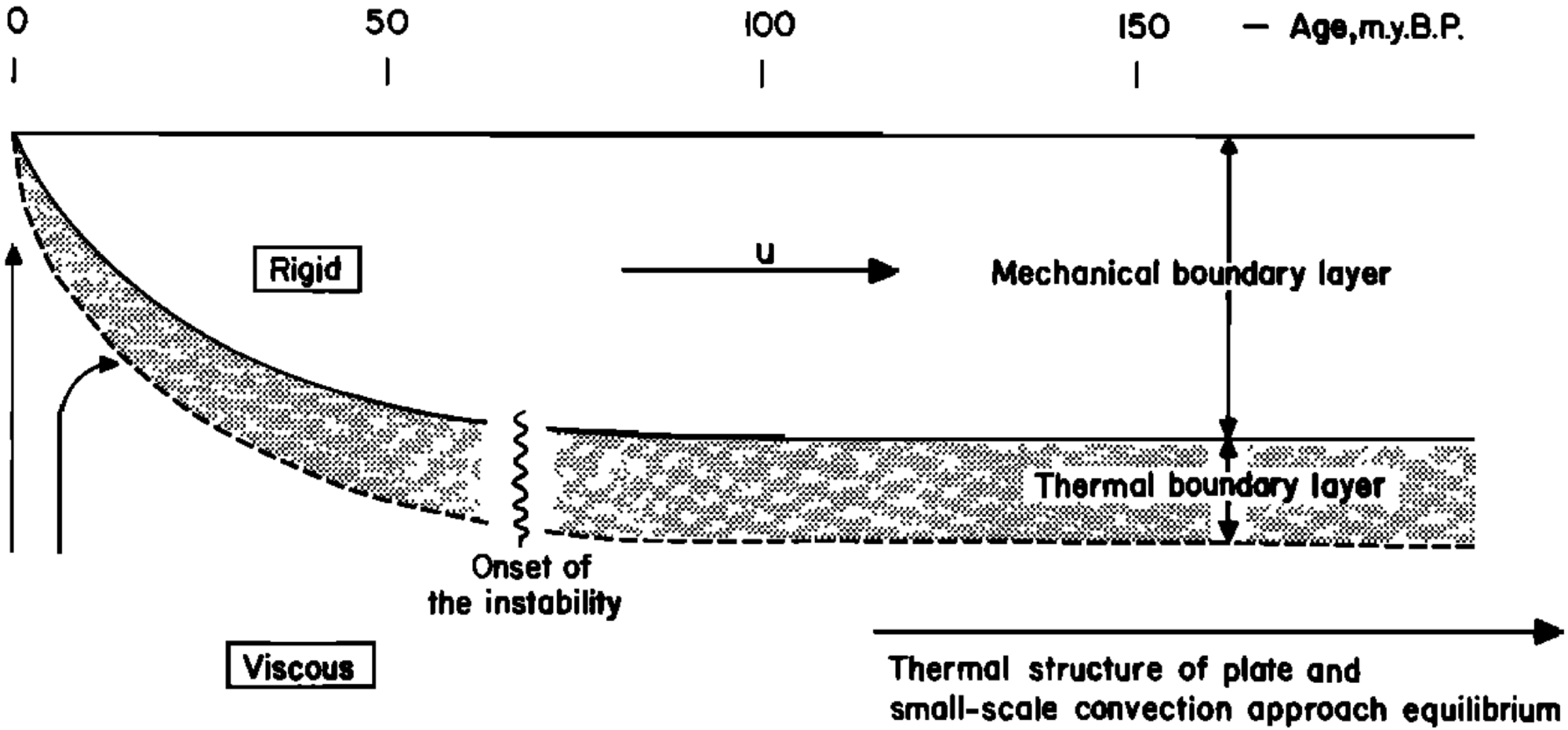

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Parsons and McKenzie are specifically describing a layer near the lithosphere-asthenosphere boundary where the combined viscosity contrasts (mechanical) and temperature contrasts lead to small scale convection.

Thermal boundary layers

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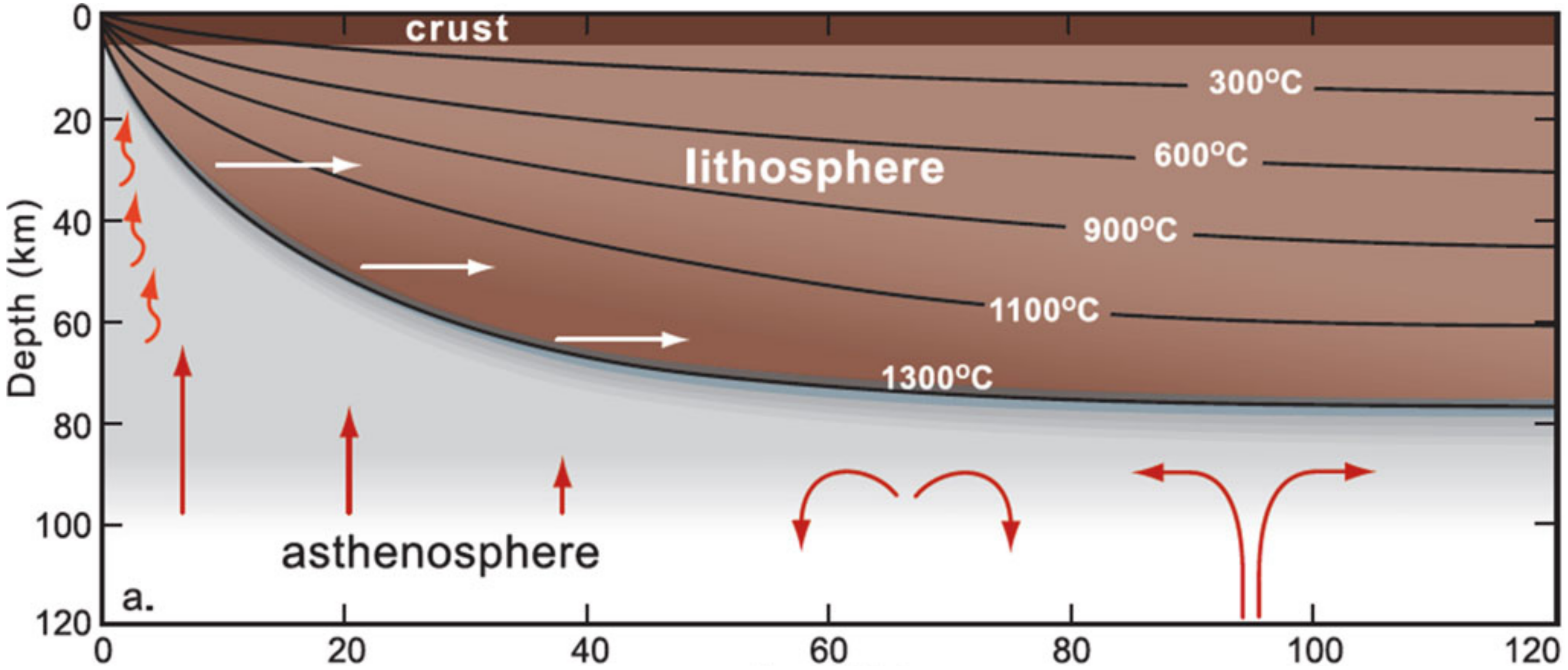

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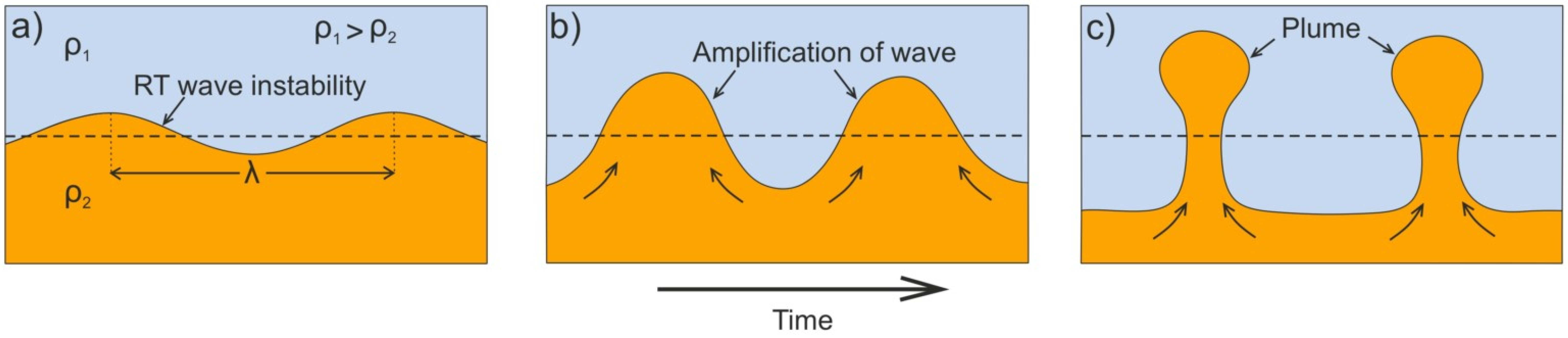

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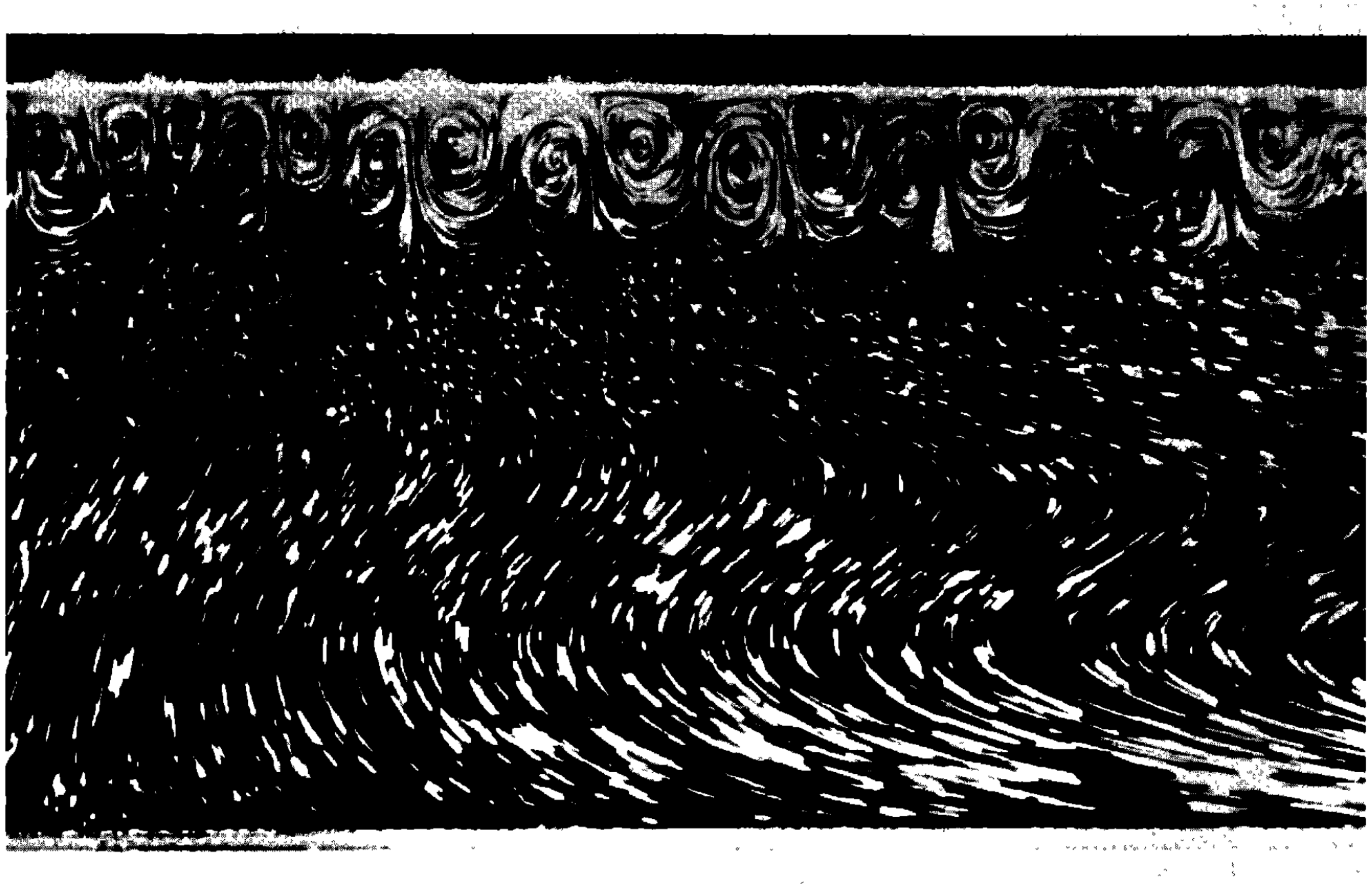

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Higher heat flux to the base of the lithosphere after the instability forms, resulting in a near constant temperature at the base of the lithosphere (the instability delivers heat as fast as conductive cooling above can remove it, a steady state).

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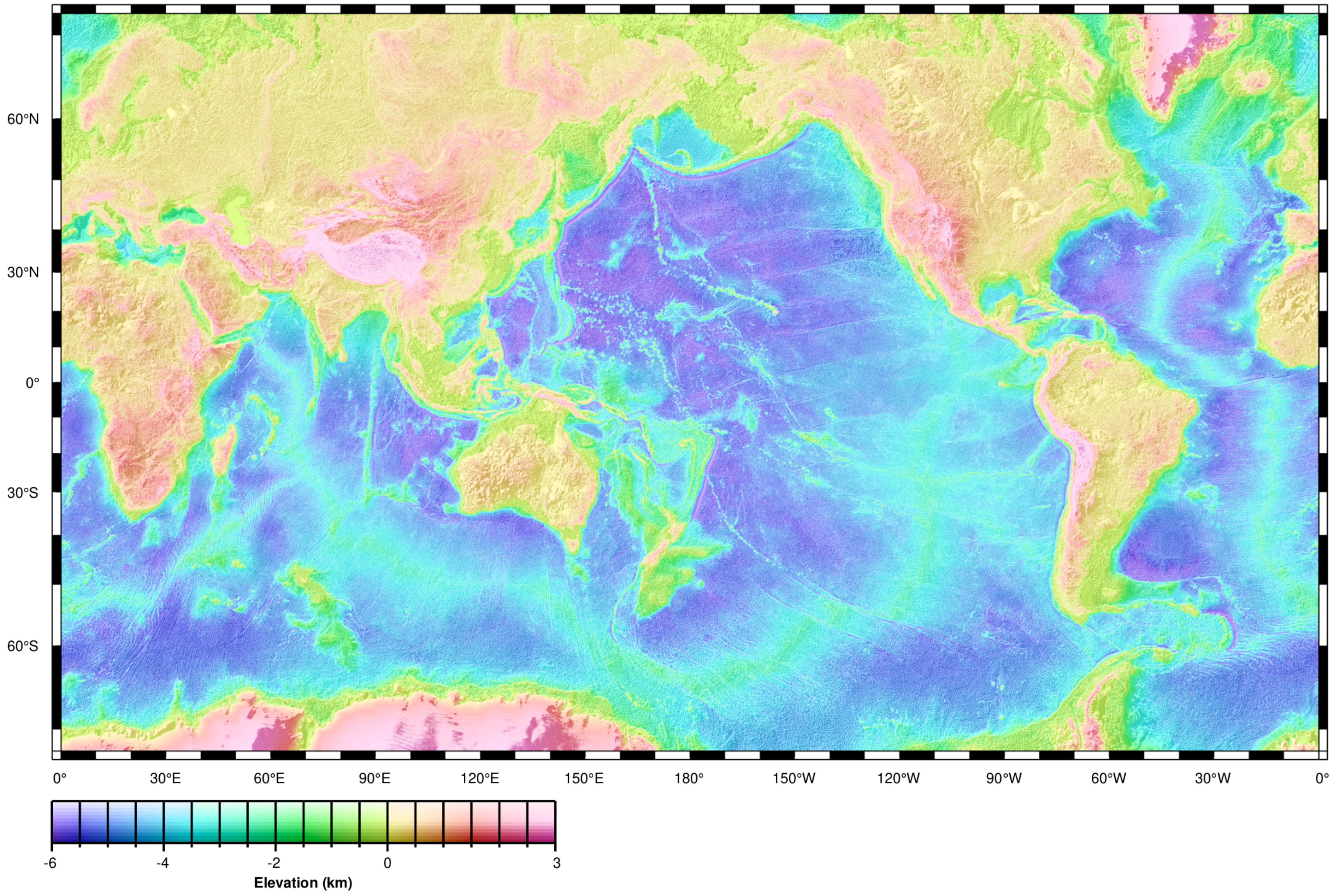
Recall our drawings of thermal profiles earlier, how does a fixed boundary condition at 100 km change the temperature profile in the lithosphere?

Mapping the sea-floor



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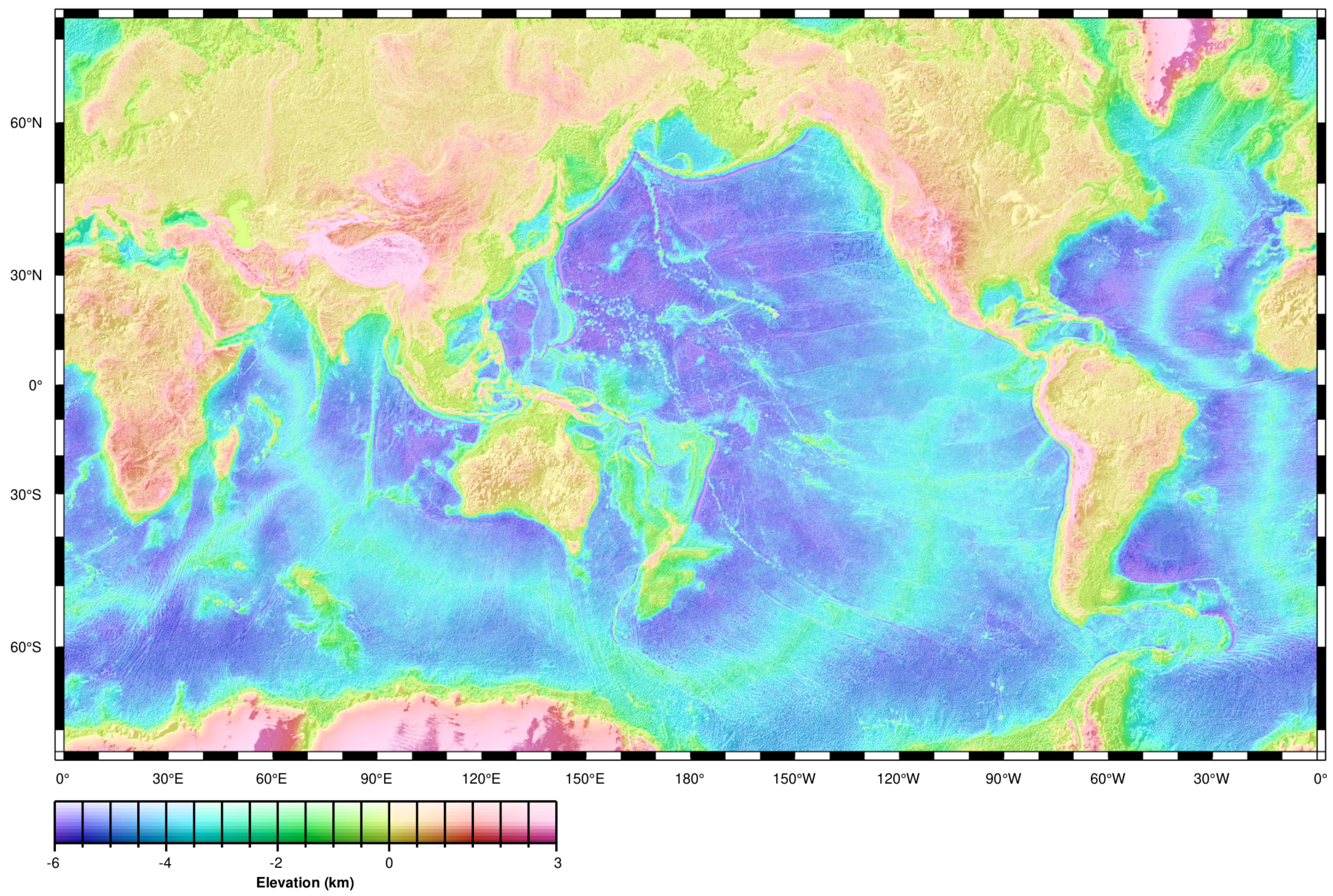
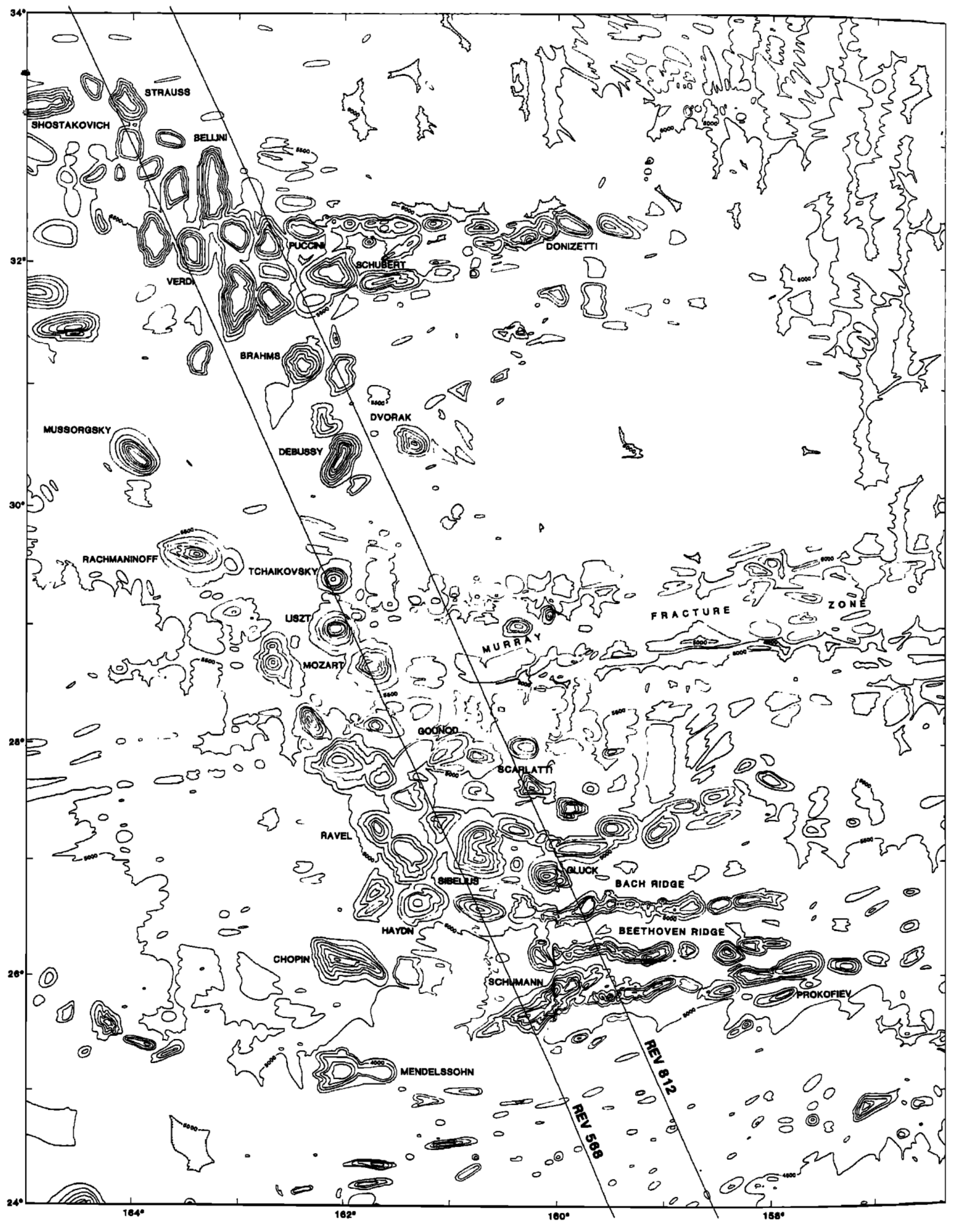


How do we map the bathymetry of the sea-floor?

A combination of:

- Depth Soundings
- Satellite Altimetry

Bathymetric Prediction From SEASAT Altimeter Data (Dixon et al. 1983)



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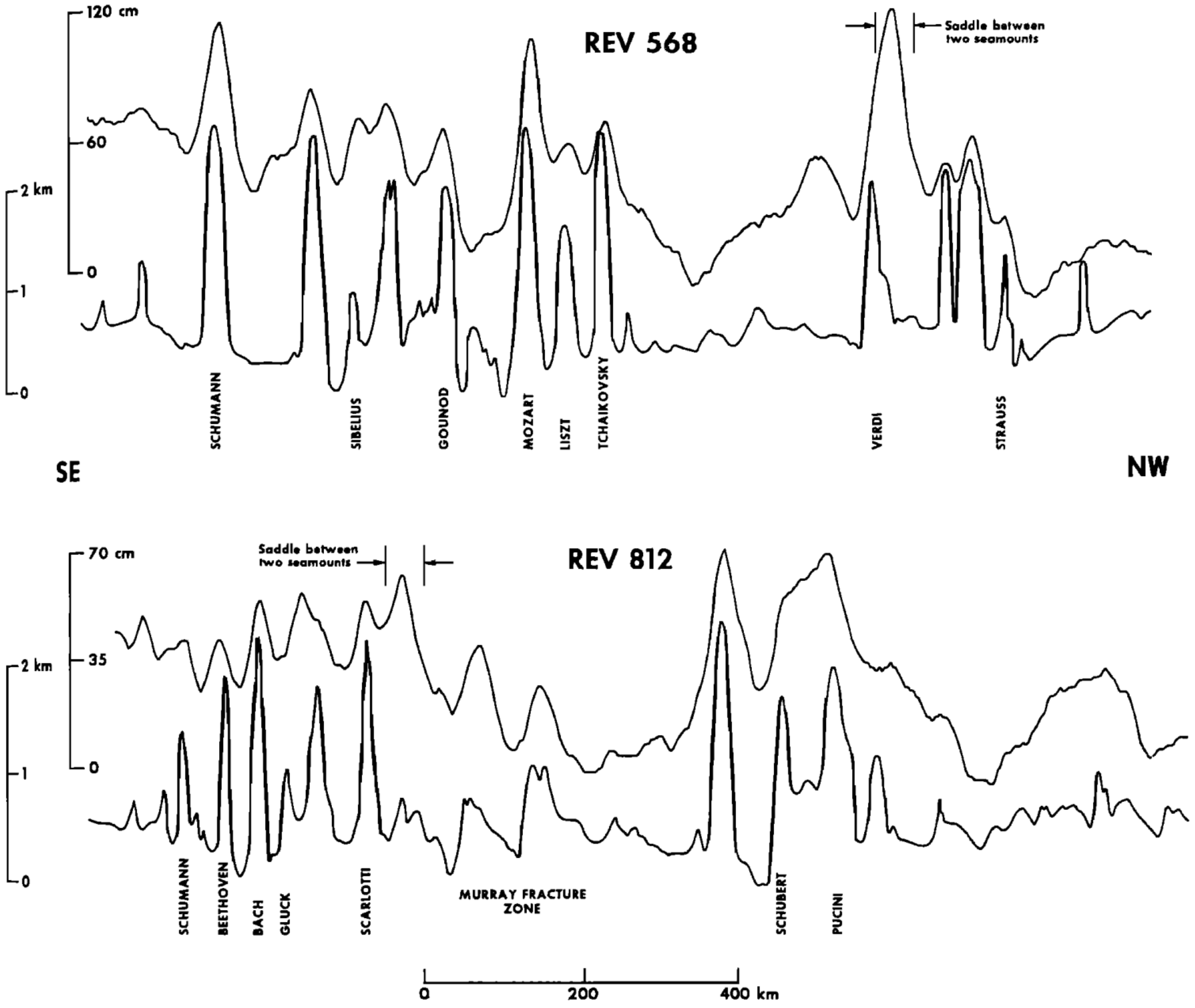

Gravitational potential

Gravitational potential is the the work (energy transferred) per unit mass that would be needed to move an object to that point from a distance infinitely far away. Recall that:

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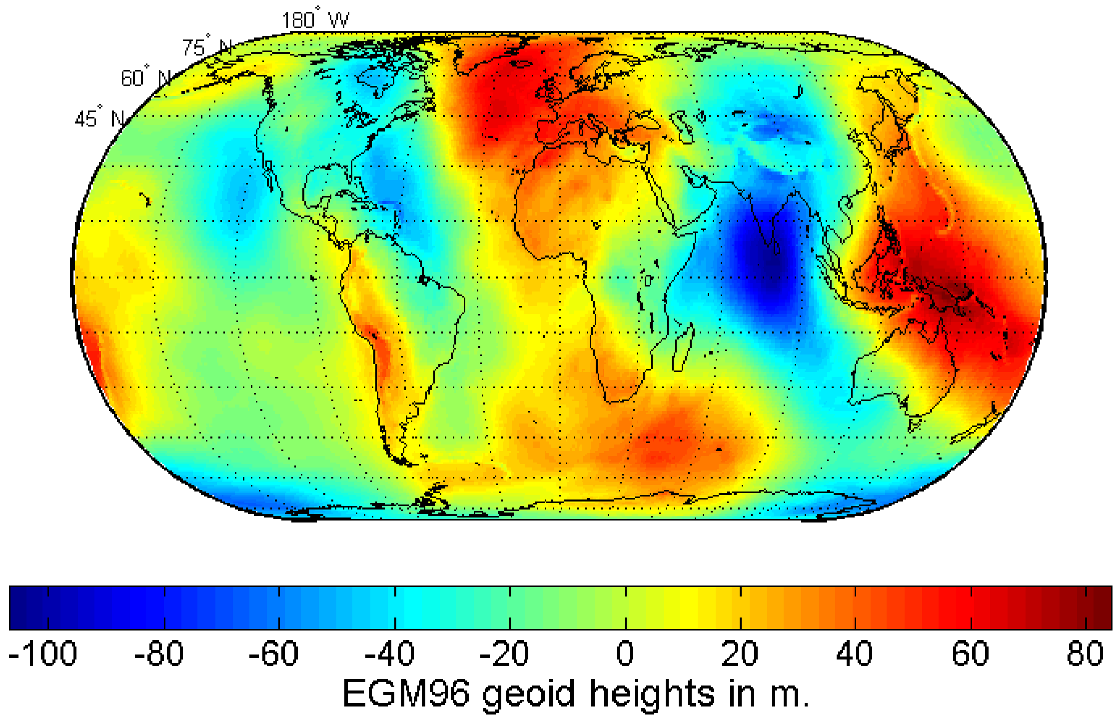

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    - very far from Earth (treat Earth as a point mass)
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- variations are small amplitude
- due to lateral differences in density
- high wavelength variations are due to difference deep in the Earth
- low wavelength variations are due to differences near the surface of the Earth

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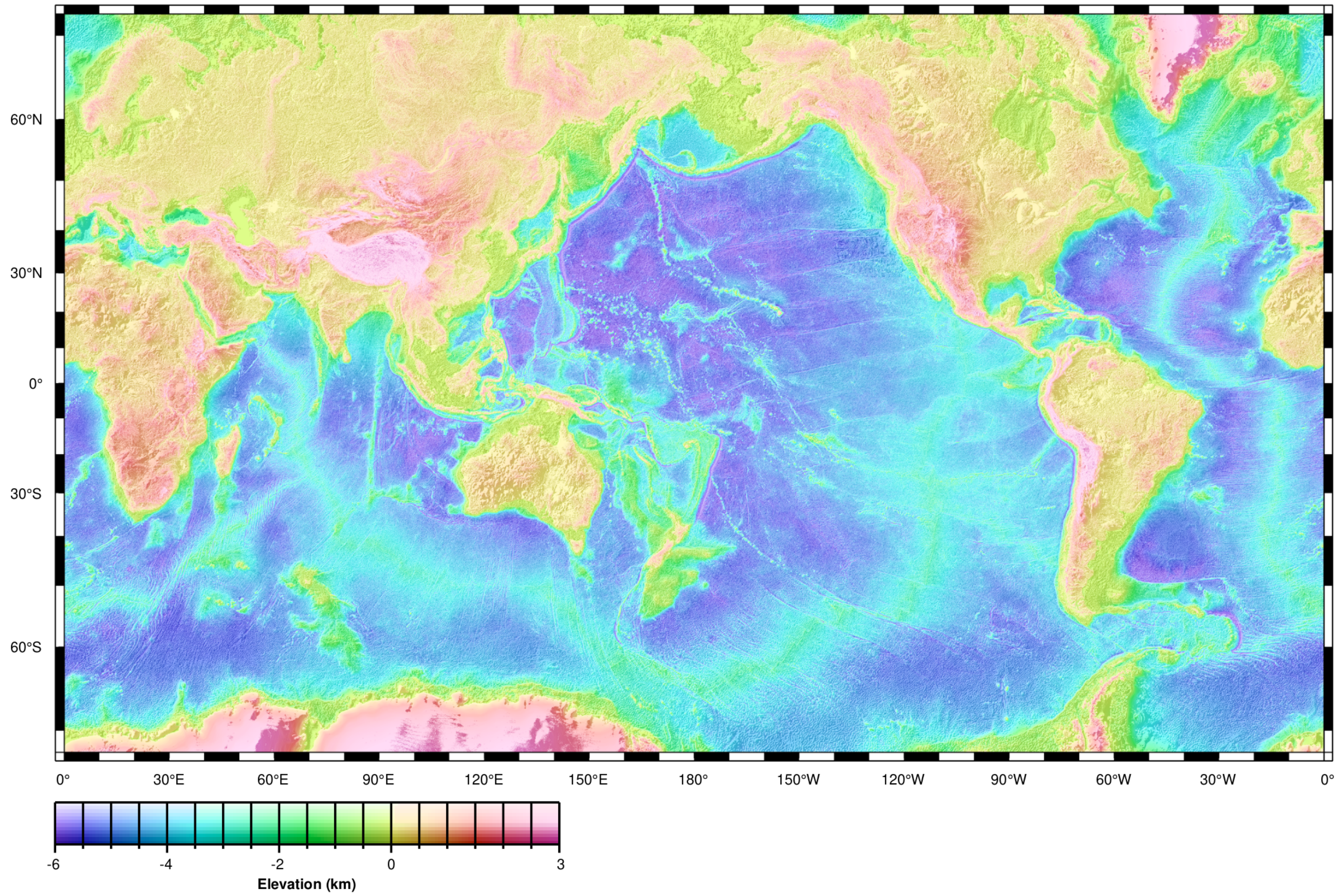
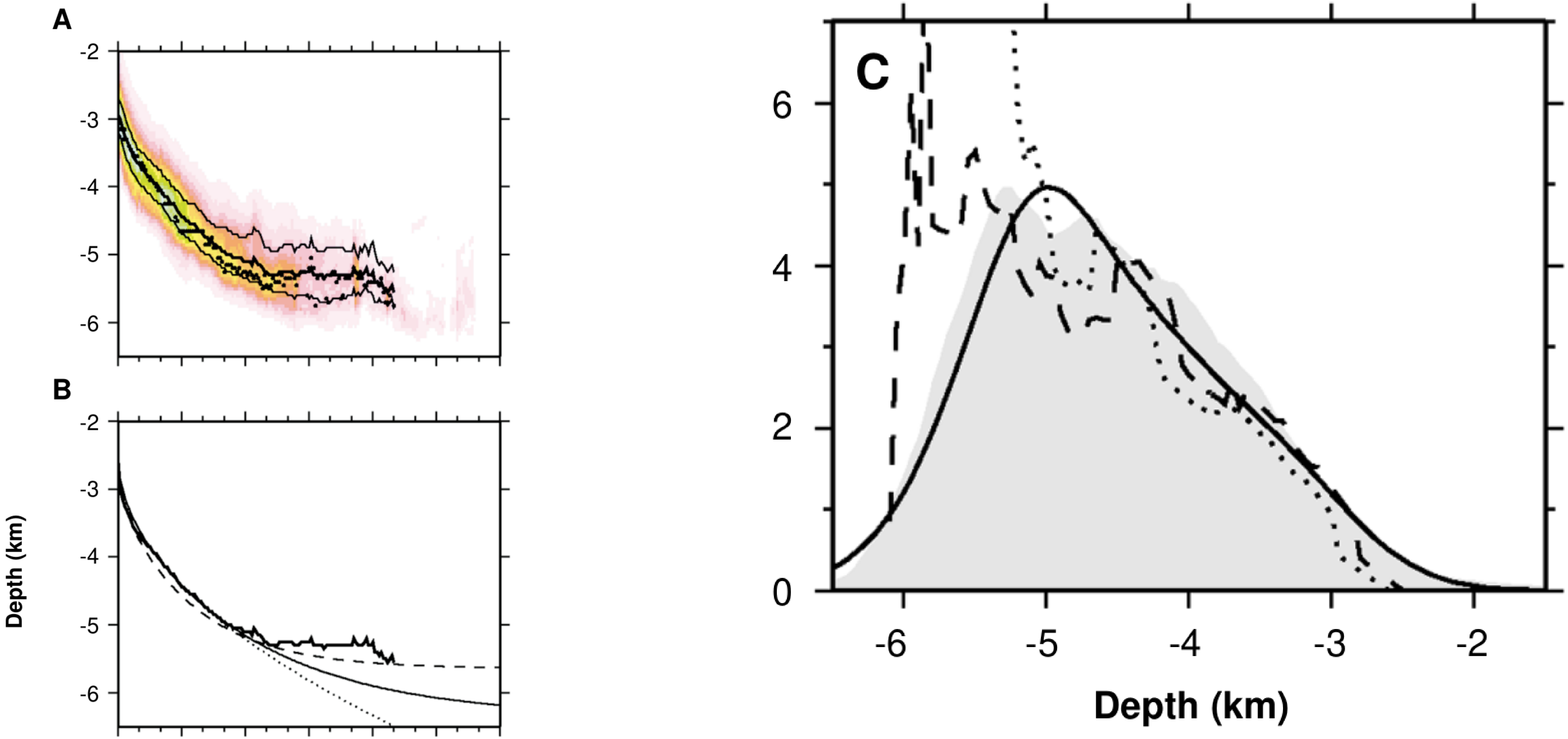


- Altimetry data decomposed into high frequency (low wavelength) and low frequency (high wavelength) *spectral* components
- Low frequency components are combined with ship soundings to estimate deeper Earth density structures
- High frequency components are used to interpolate between soundings, assuming deep structure constant
- High frequency components are used to resolve very shallow density contrasts (such as sea-mounts)

Returning to the plate model and old oceanic lithosphere



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