Thermal modelling of the lithosphere and asthenosphere

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Turcotte and Oxburgh, 1967

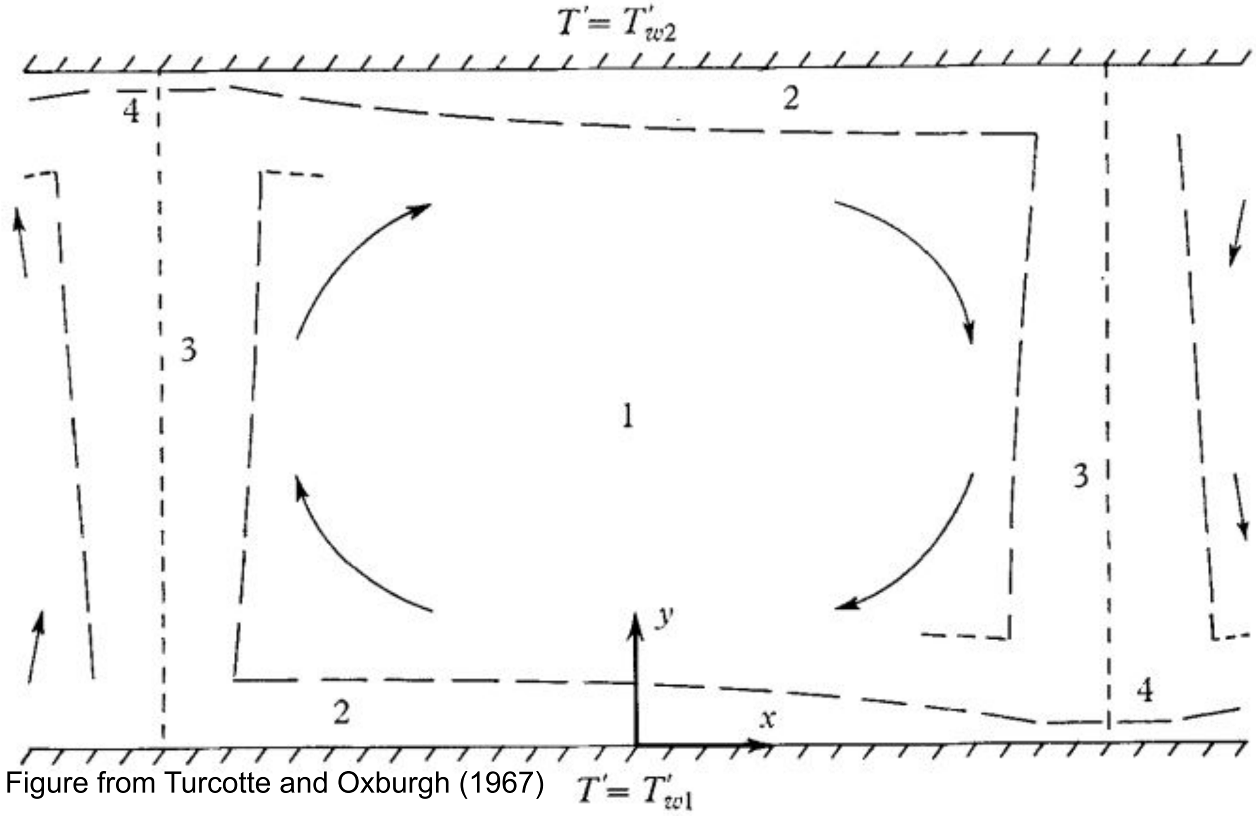


Figure from Turcotte and Oxburgh (1967)

- Lithosphere as a conductive thermal boundary layer above a convective mantle

Turcotte and Oxburgh, 1967

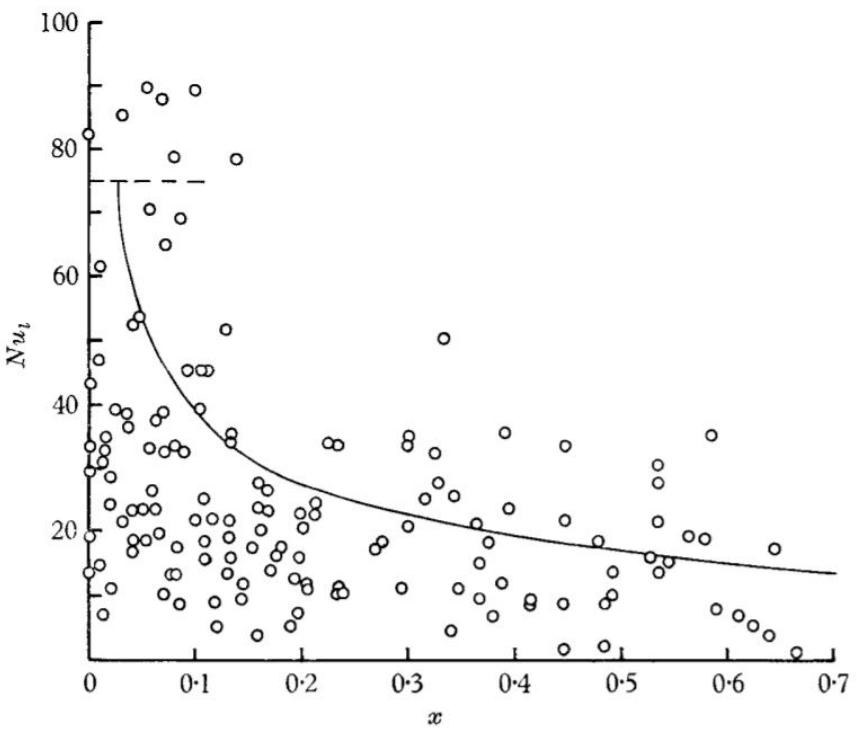
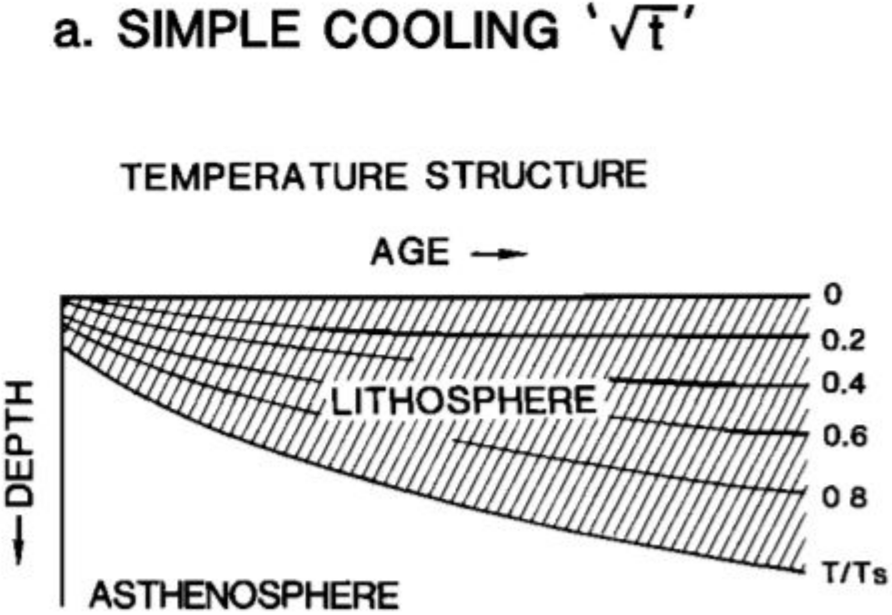
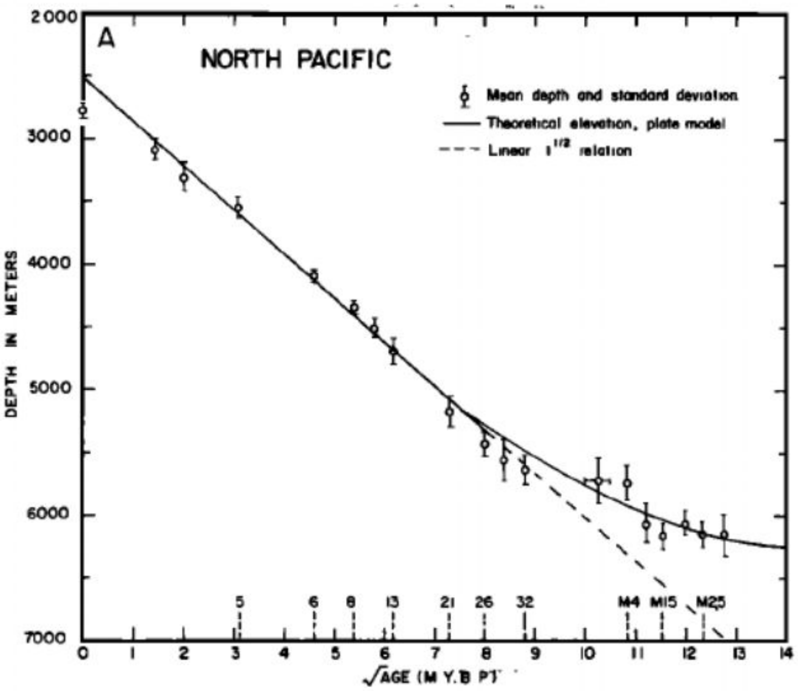


Figure from Turcotte and Oxburgh (1967)

- Conservation equations
- Nusselt number
- East Pacific Rise from Lee and Uyeda (1965)
- Calculate velocity of continental drift

Simple conductive cooling model





Figures (left) from Renkin and Sclater (1988) and (right) from Parsons and Sclater (1977)

McKenzie, 1967

- Accounts for flattening of oceanic seafloor
- Constant temperature at the bottom and constant thickness of the layer
- Knows thermal properties of the layer, calculate the temperature and depth-age relationship

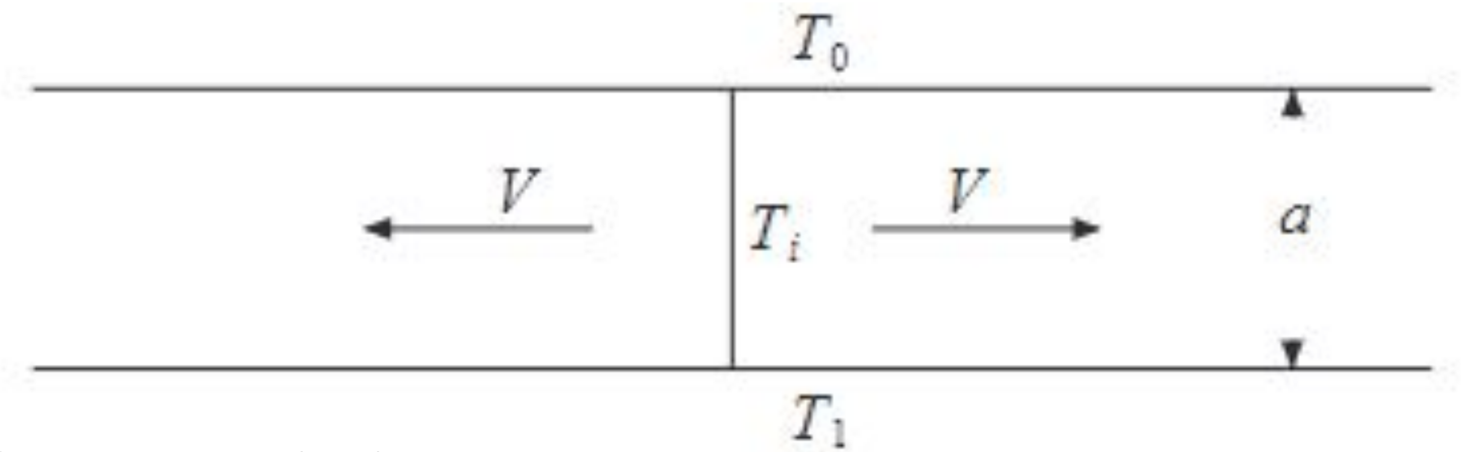


Figure from McKenzie et al. (2005)

Governing equations

$$\rho C_P\left[\frac{\partial T}{\partial t} + \mathbf{v}\cdot\nabla T\right] = \kappa\nabla^2 T + H$$

$$\nabla\cdot\mathbf{u} = 0$$

$$\frac{\mu}{\rho}\nabla^2\mathbf{u} - g\mathbf{a}_z - \frac{1}{\rho}\nabla P = 0$$

Plate model

- Parsons and McKenzie, 1978
- Convection that transport heat to the bottom of the mechanical layer

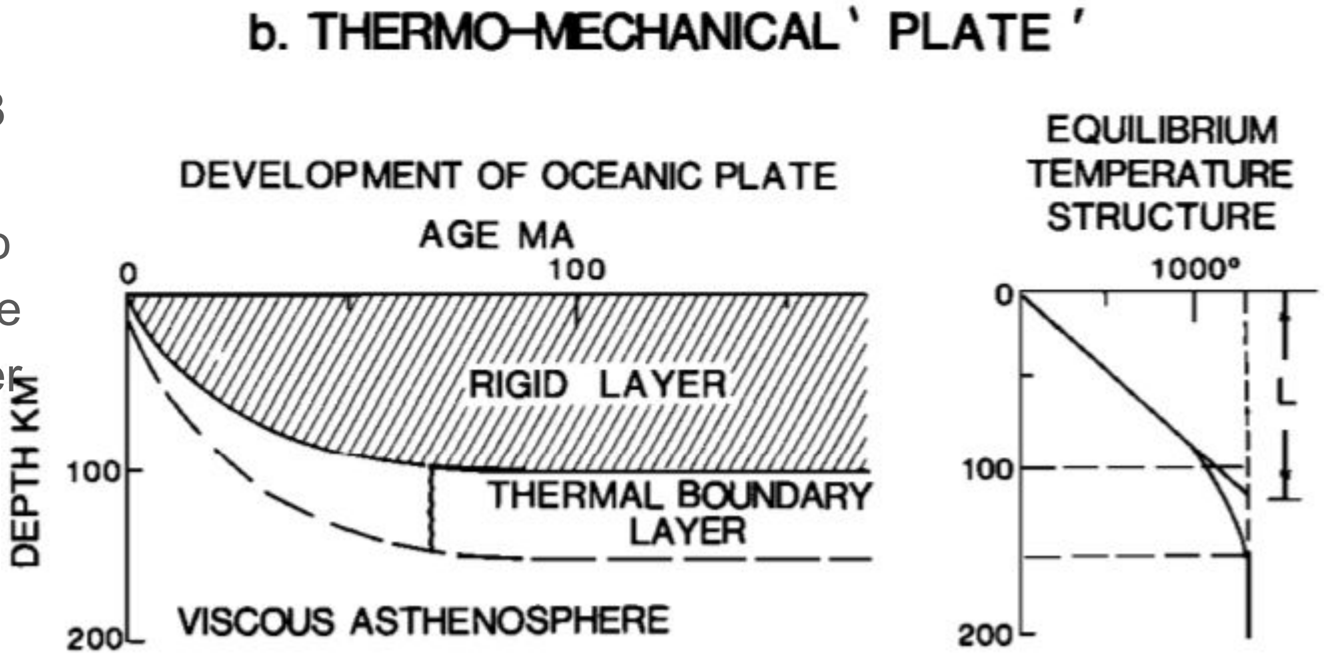
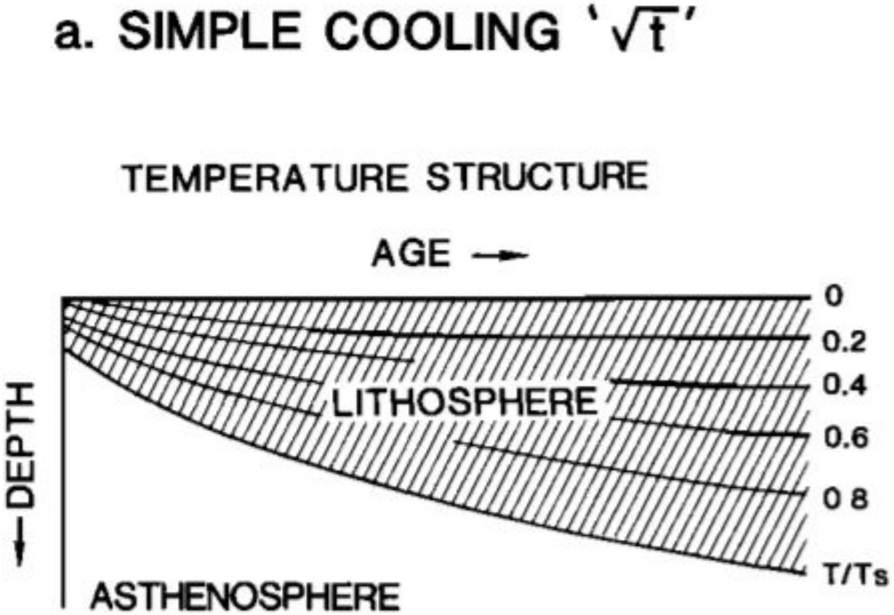
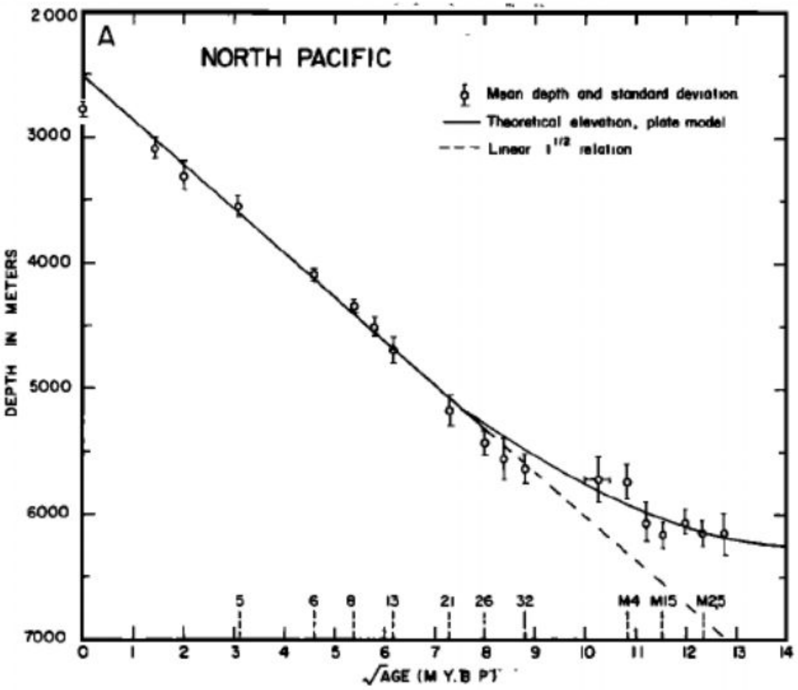


Figure from Renkin and Sclater (1988)

Simple conductive cooling model





Figures (left) from Renkin and Sclater (1988) and (right) from Parsons and Sclater (1977)

Hot spot as a mechanism that transport heat

- Studies with hot spot in different oceans
  - Heestand and Crough (1981)
  - Hayes (1988)
- Different filtering methods used to exclude seafloor influenced by volcanism obtain different depth-age relationship

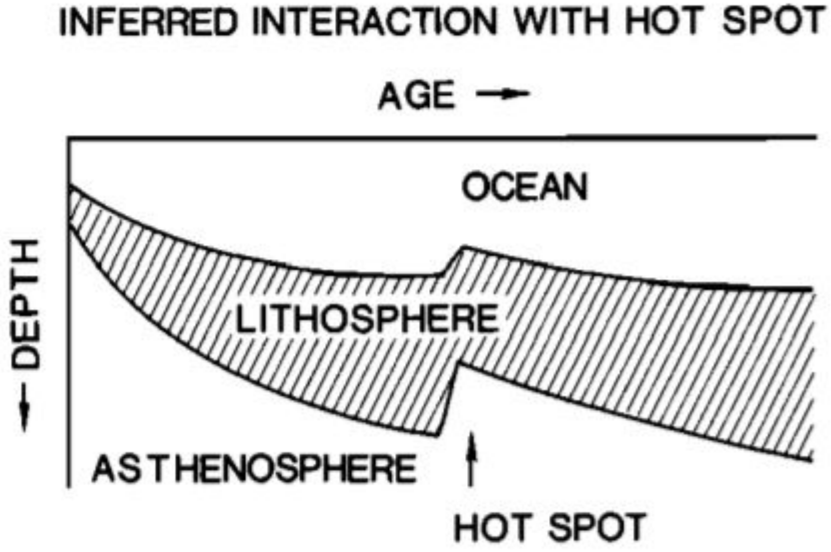


Figure from Renkin and Sclater (1988)

Hot spots

- Hillier and Watts (2005)
    - By eye
- Crosby et al. (2006)
    - Absence of gravity anomaly

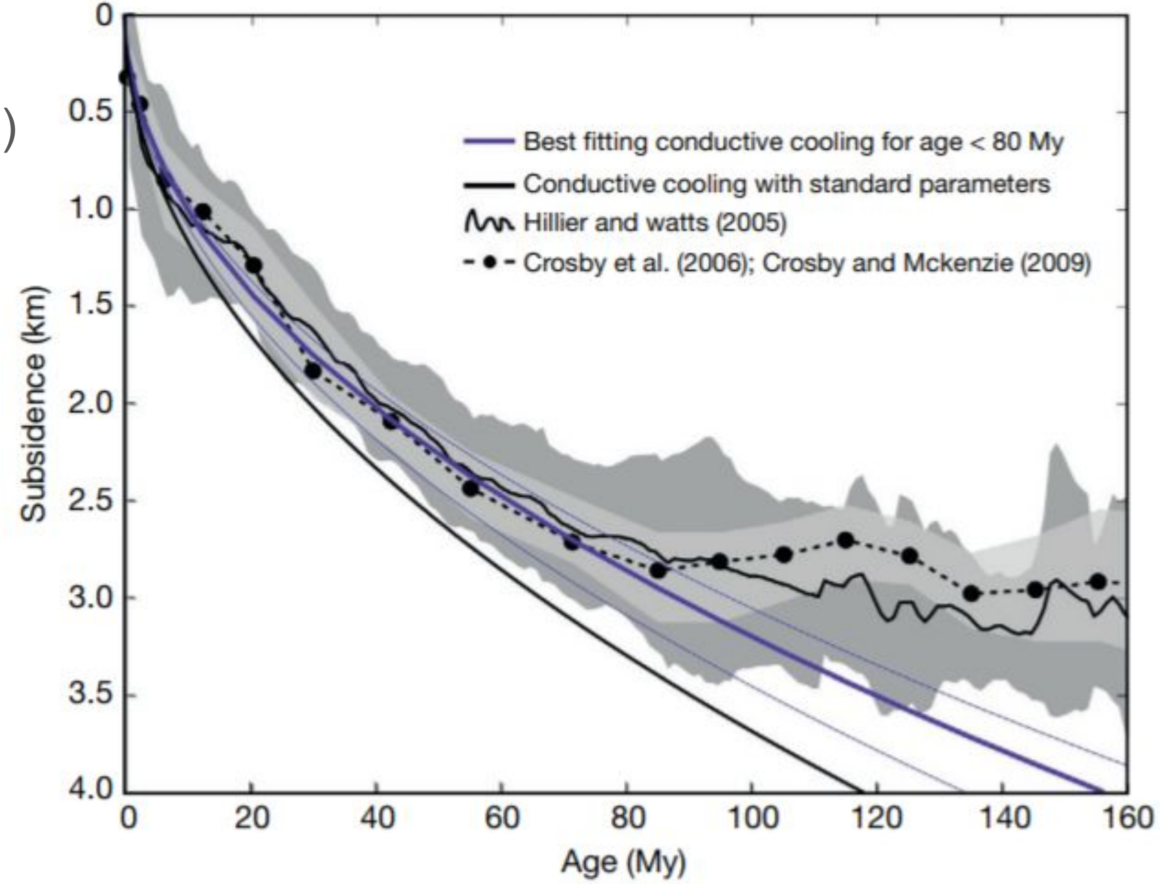


Figure from Parmentier et al. (2015)

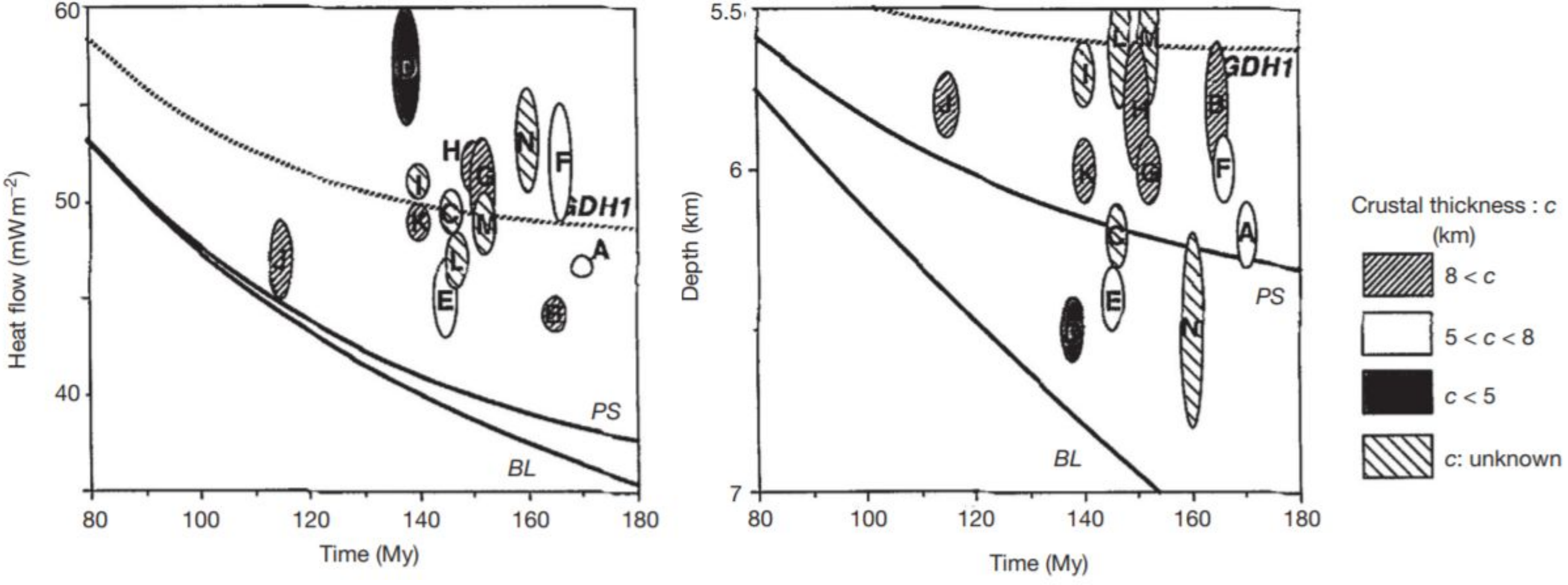


Figure from Nagihara et al. (1996)

Small scale convective instability

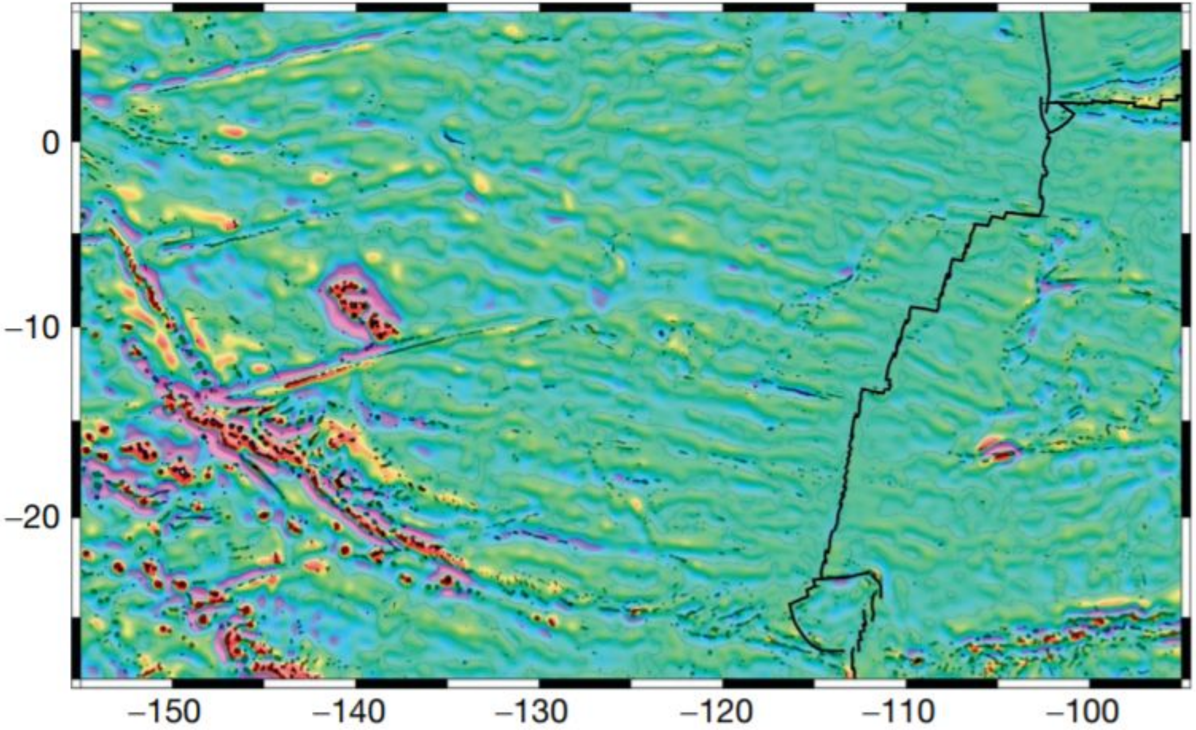


Figure from Sandwell and Fiaiko (2004)

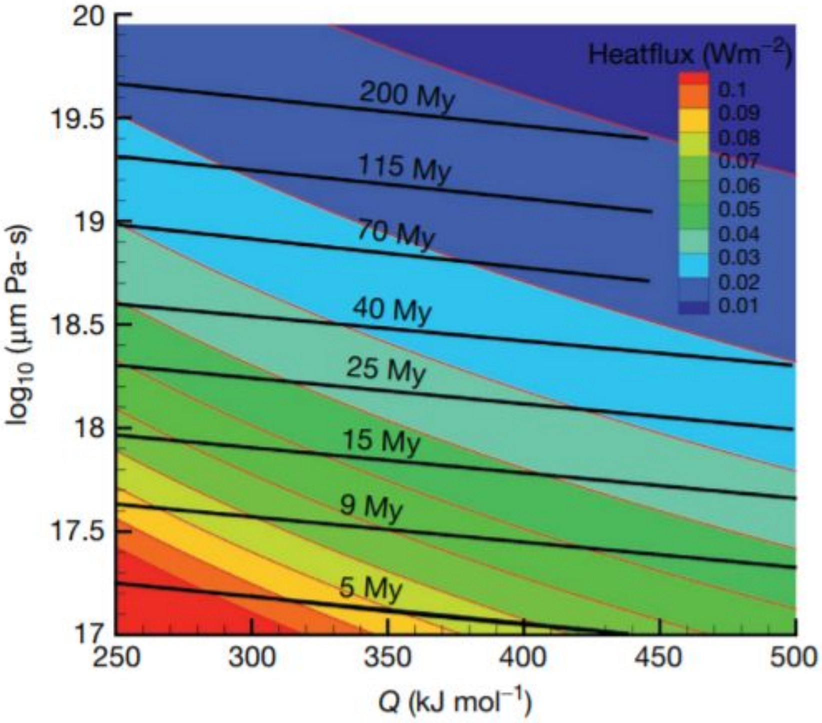
- Haxby and Weissel, (1986), Pacific
- Onset time

Doin and Fleitout, 1996

- a uniform heat flux supplied to the bottom of the thermal boundary layer explains depth–age relationship well

Davaille and Jaupart, 1994

- scaling laws for convective onset time (age) and heat flow in a viscous fluid with strongly temperature-dependent viscosity cooled from above
- Q = 250 kJ/mol, T = 1300 C, predicts a onset time of 52-65 Ma.
- Numerical models predicts shorter onset times.



Onset time of small-scale convective instability

- Spreading rate
- Sandwell and Schubert (1980) in Atlantic and SE Indian ocean
- High shear strain produces smaller grain size which is in favor of fast diffusion creep with lower viscosity or higher stress in favor of dislocation creep with large Q
- Water content

2D vs. 3D models

- van Hunen et al. (2003) studied 3D convective instability beneath a moving plate

Summary

- Parmentier, E. M. (2015), 7.08 - The Dynamics and Convective Evolution of the Upper Mantle A2 - Schubert, Gerald, in Treatise on Geophysics (Second Edition), edited, pp. 319-337, Elsevier, Oxford, doi:10.1016/B978-0-444-53802-4.00131-7.
- There isn’t one mechanism of heat transfer that can account for all observations related to heating the lithosphere everywhere on Earth.
- The relative importance of hot spot and convective instability depends on spreading rate and mantle rheology.