SUMMER INSTITUTE: USING PARTICLE PHYSICS TO UNDERSTAND AND IMAGE THE EARTH

11-21 July 2016 *Gran Sasso Science Institute*
Europe/Rome timezone

Basics of heat flow

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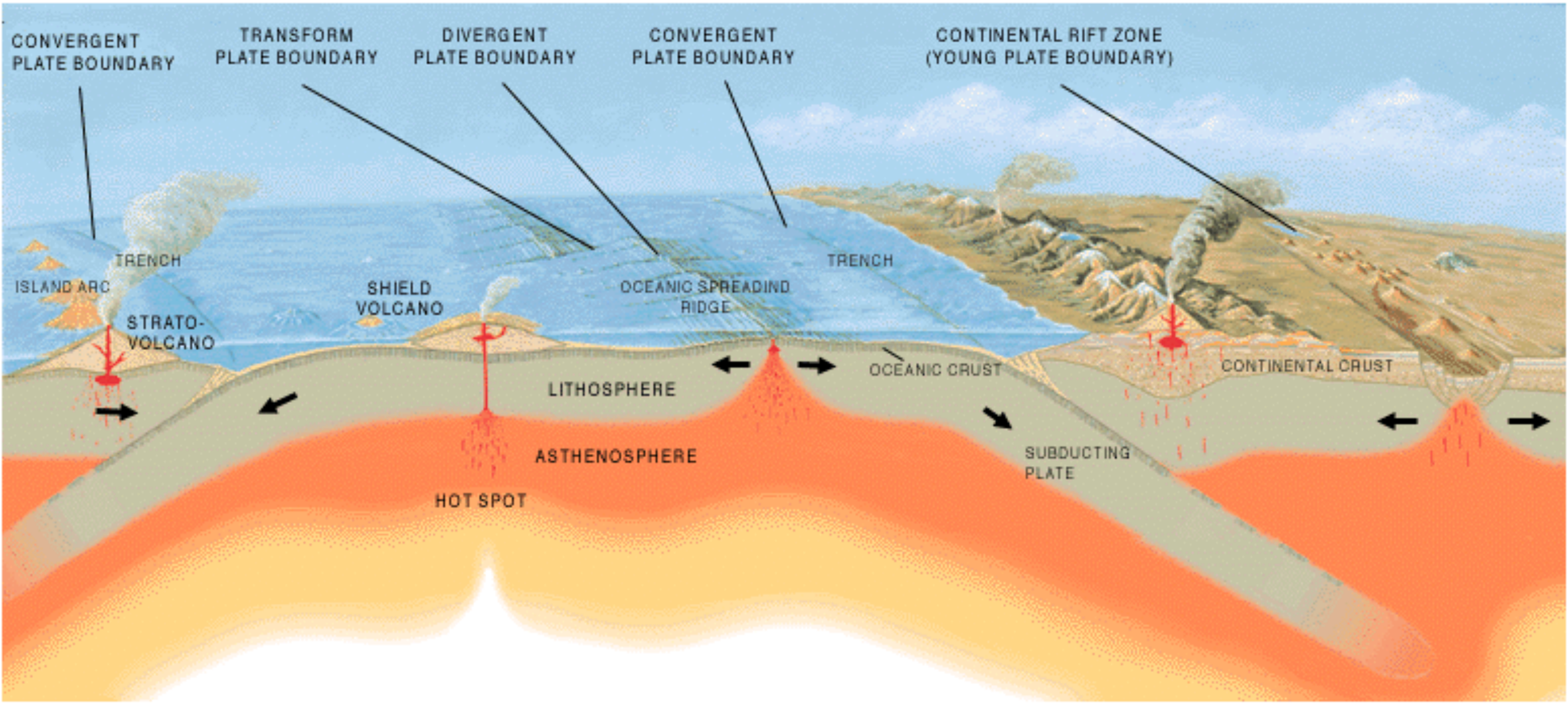
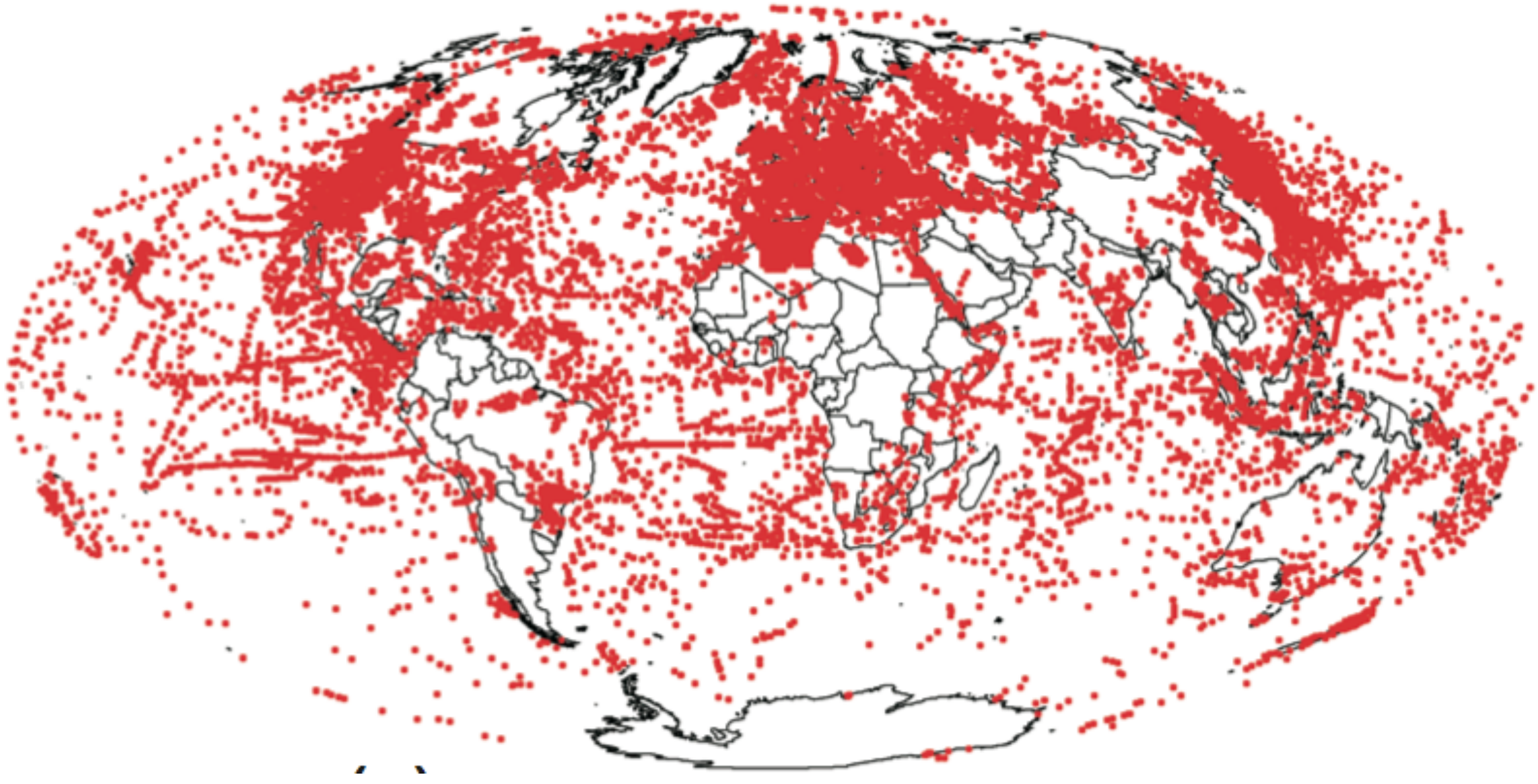
What is the heat output from solid Earth?


CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADIND RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
SUBDUCTING PLATE

Heat flow measurement sites

~38000 measurement sites



Davies & Davies 2010

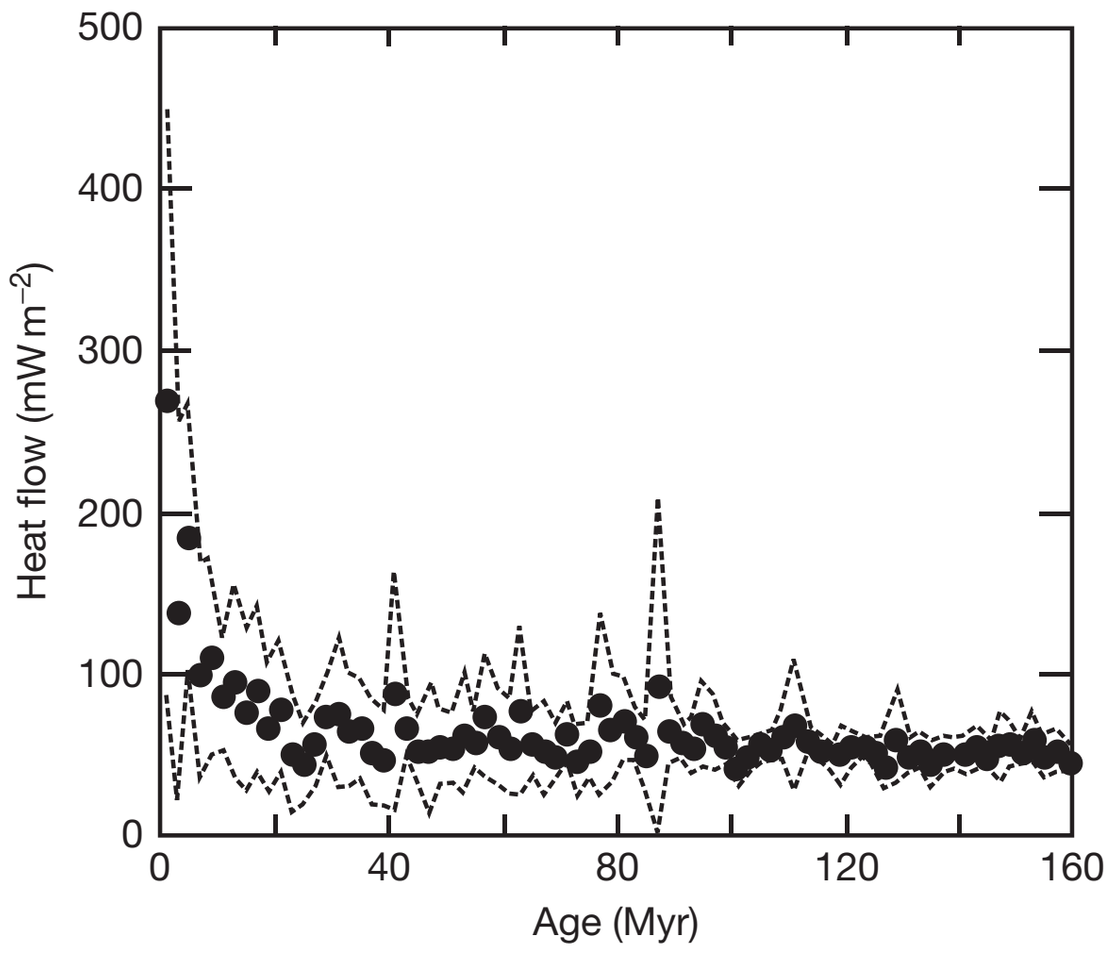
Heat flow in oceanic areas

Measurements by

- probe technique
- deep-sea drill holes (limited number)

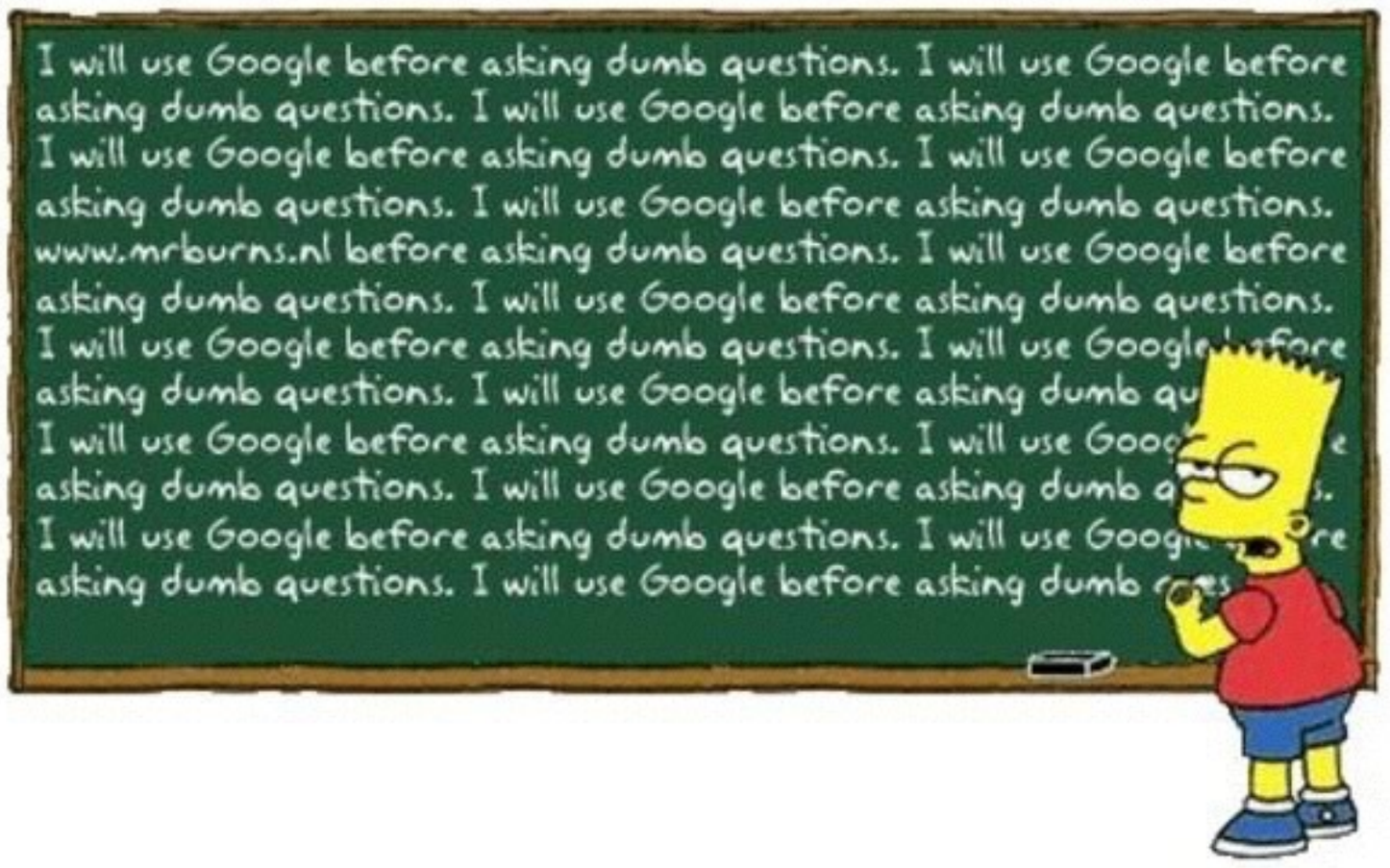
Measures conductive heat flux

Does not account for heat transport by water flow through fractures and porous rock near mid-oceanic ridges



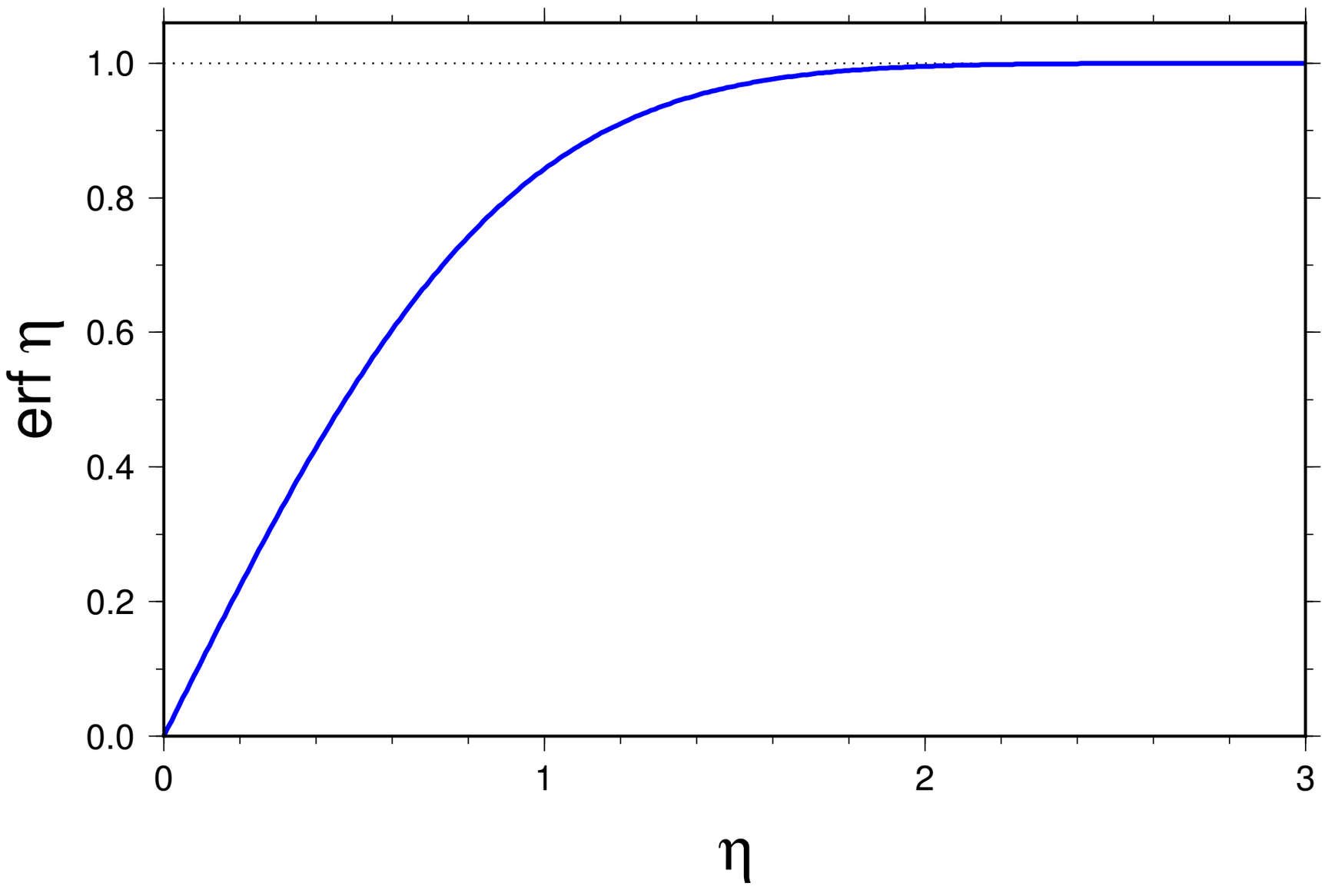
Jaupart et al. 2015 in Treatise on Geophysics

Cooling of semi-infinite half-space

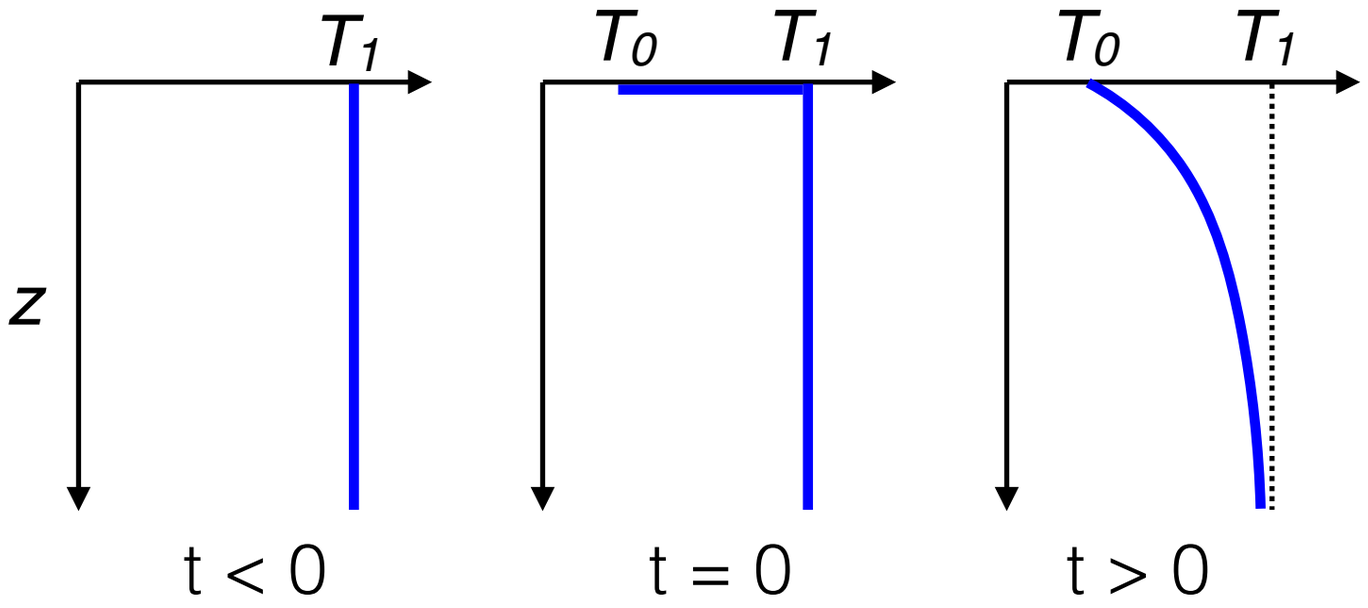


Error function

$$\operatorname{erf}\eta = \frac{2}{\sqrt{\pi}} \int_0^\eta \mathrm{e}^{-\xi^2}\,\mathrm{d}\xi$$



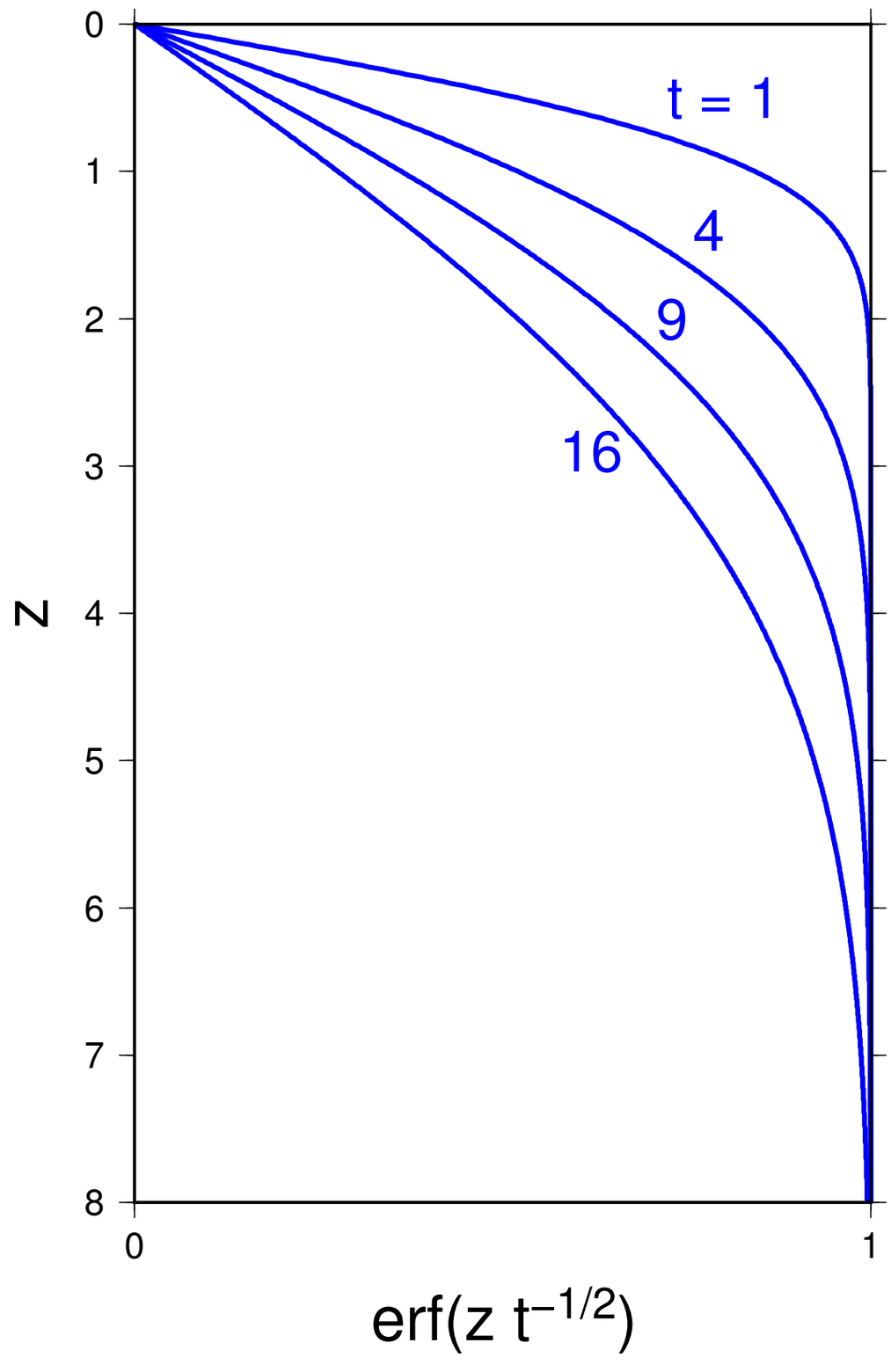
Cooling of semi-infinite half-space



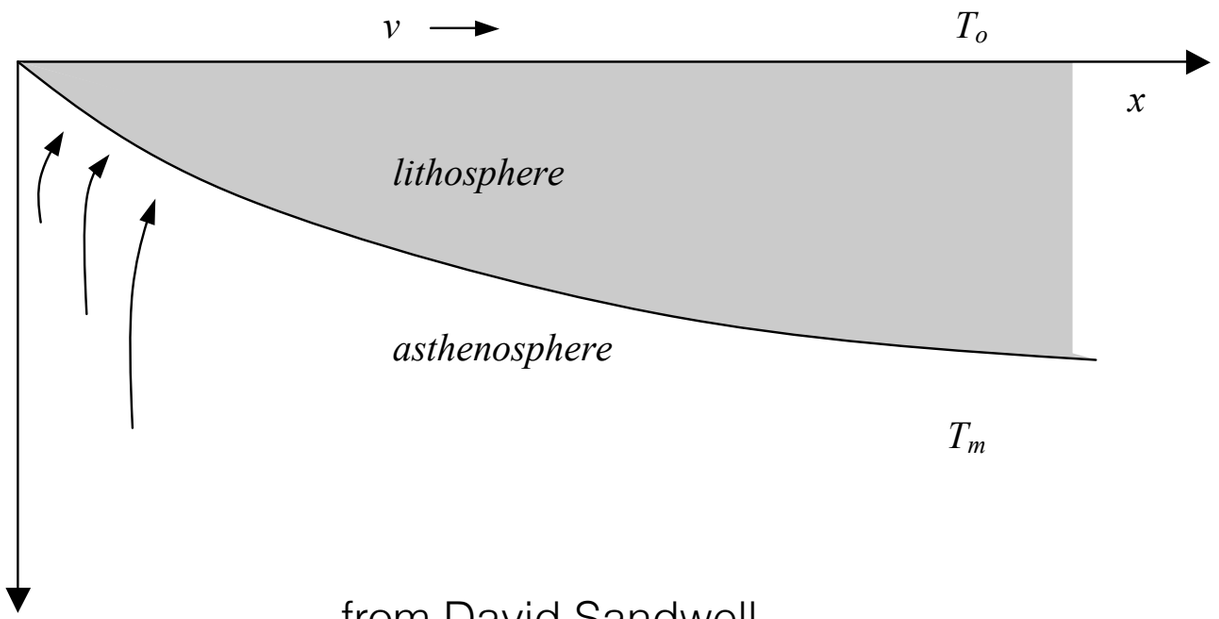
$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2}$$

$$\frac{T - T_0}{T_1 - T_0} = \operatorname{erf}\left(\frac{z}{2\sqrt{\kappa t}}\right)$$

$$q\big|_{z=0} = -k\frac{\partial T}{\partial z}\bigg|_{z=0} = -\frac{k(T_1 - T_0)}{\sqrt{\pi \kappa t}}$$



Cooling of oceanic lithosphere



from David Sandwell

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2}$$

$$\downarrow$$

$$v\frac{\partial T}{\partial x} = \kappa \left(\frac{\partial^2 T}{\partial z^2} + \cancel{\frac{\partial^2 T}{\partial x^2}} \right)$$

$$\frac{T - T_0}{T_1 - T_0} = \mathrm{erf}\left(\frac{z}{2\sqrt{\kappa t}}\right)$$

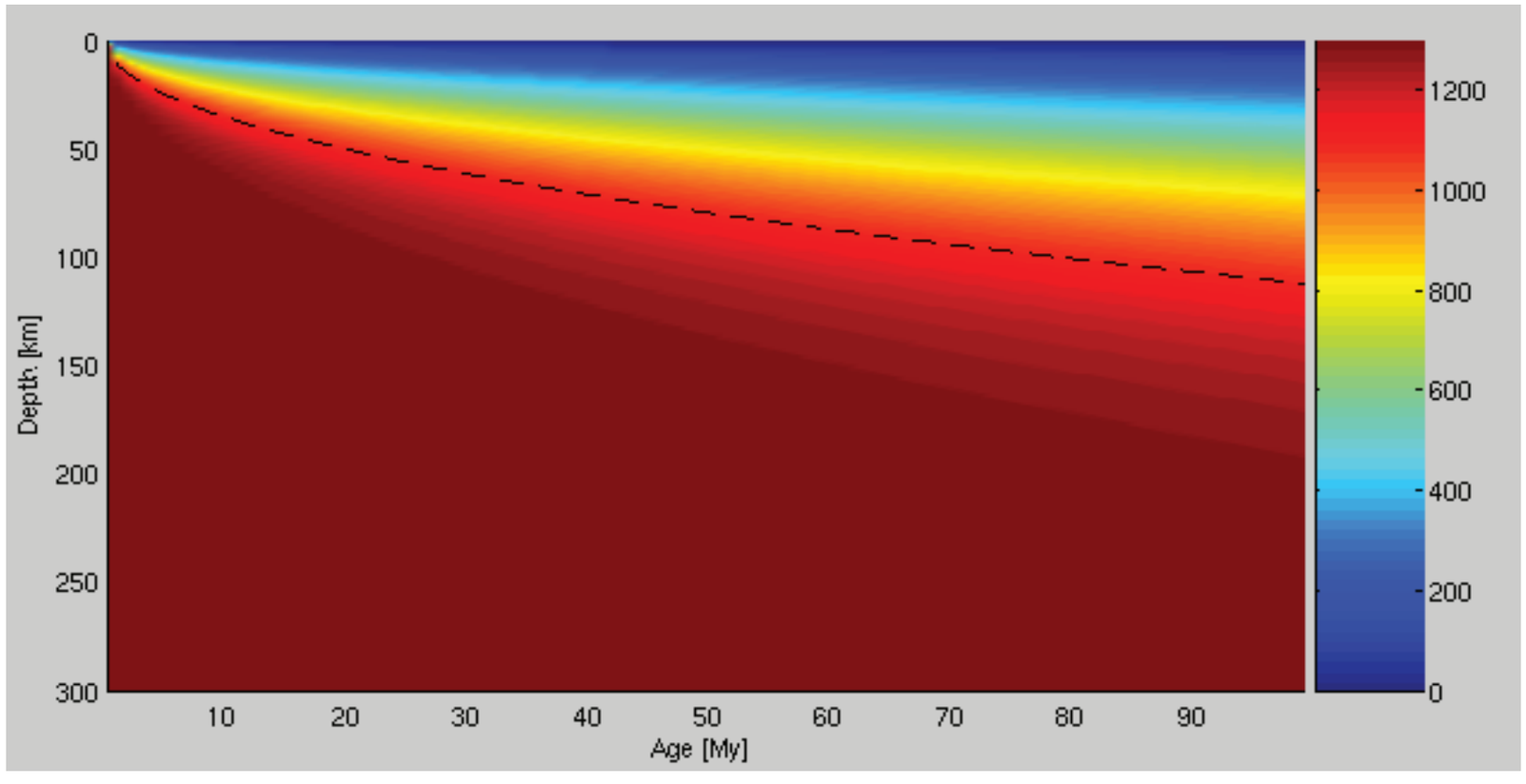
$$q\big|_{z=0} = -k\frac{\partial T}{\partial z}\bigg|_{z=0} = -\frac{k(T_1 - T_0)}{\sqrt{\pi \kappa t}}$$

$$t \rightarrow \frac{x}{v}$$

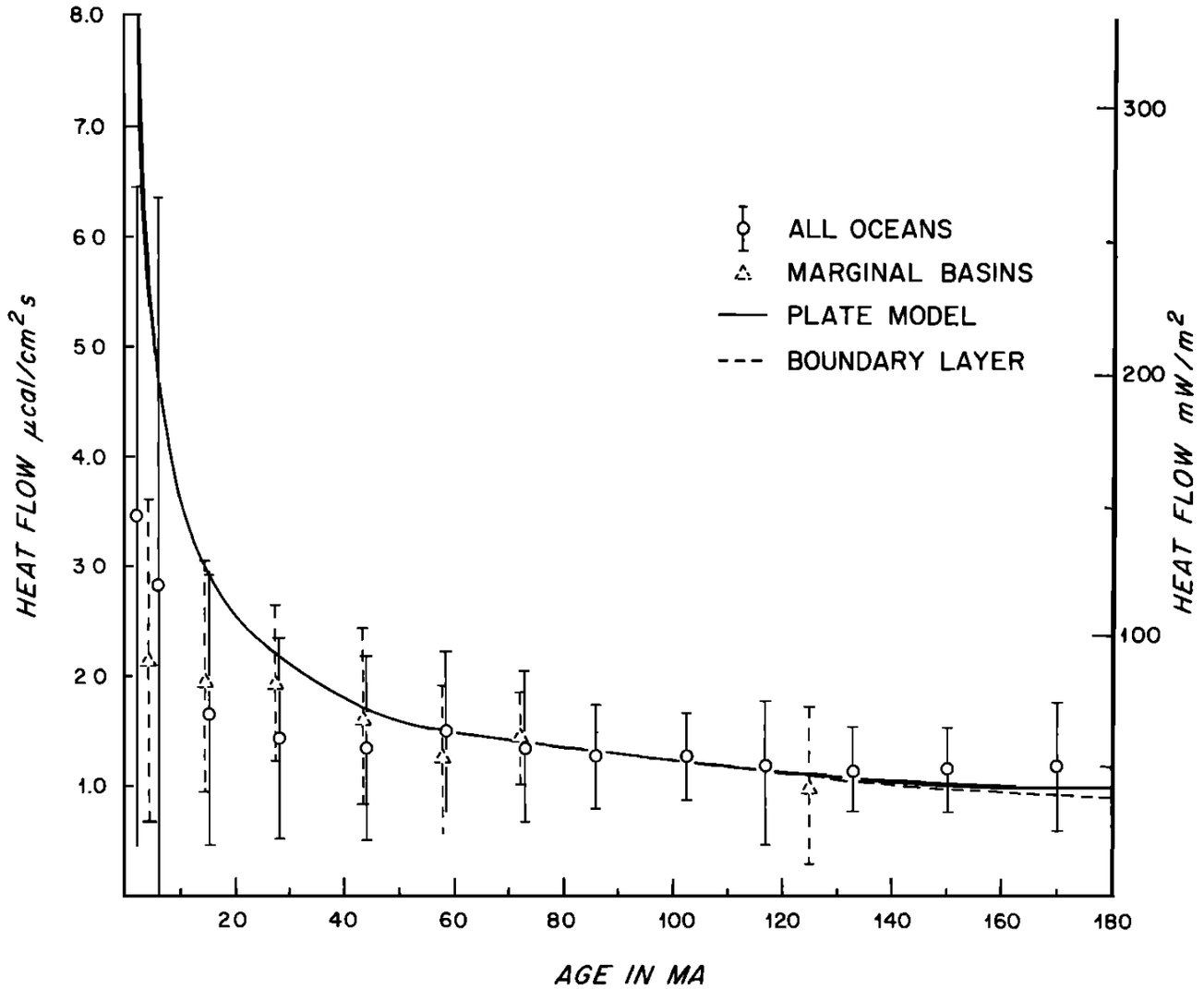
age of the lithosphere

Cooling of oceanic lithosphere

$$\frac{T - T_0}{T_1 - T_0} = \mathrm{erf}\left(\frac{z}{2\sqrt{\kappa t}}\right)$$



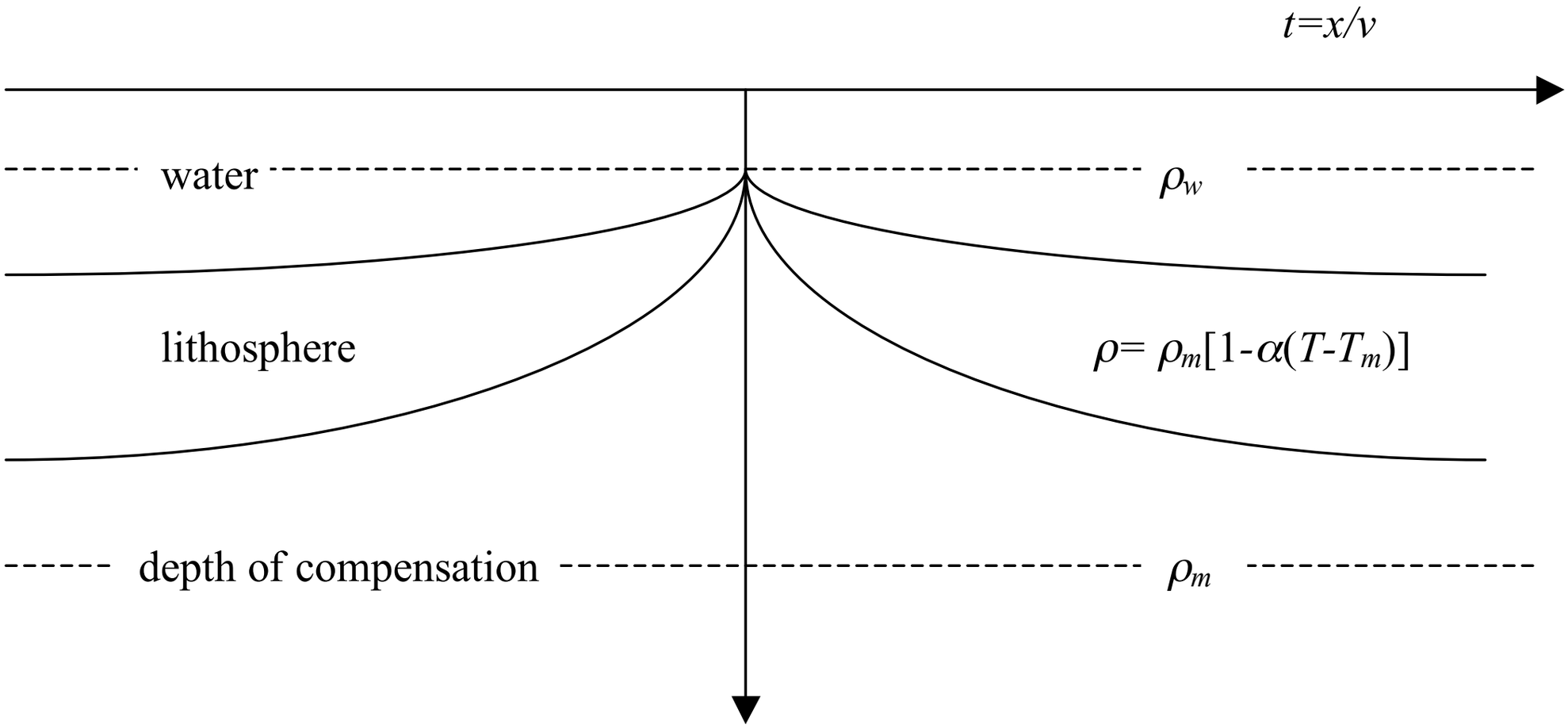
Oceanic heat flow vs. age



$$q\big|_{z=0} = -k\frac{\partial T}{\partial z}\bigg|_{z=0} = -\frac{k(T_1 - T_0)}{\sqrt{\pi\kappa t}}$$

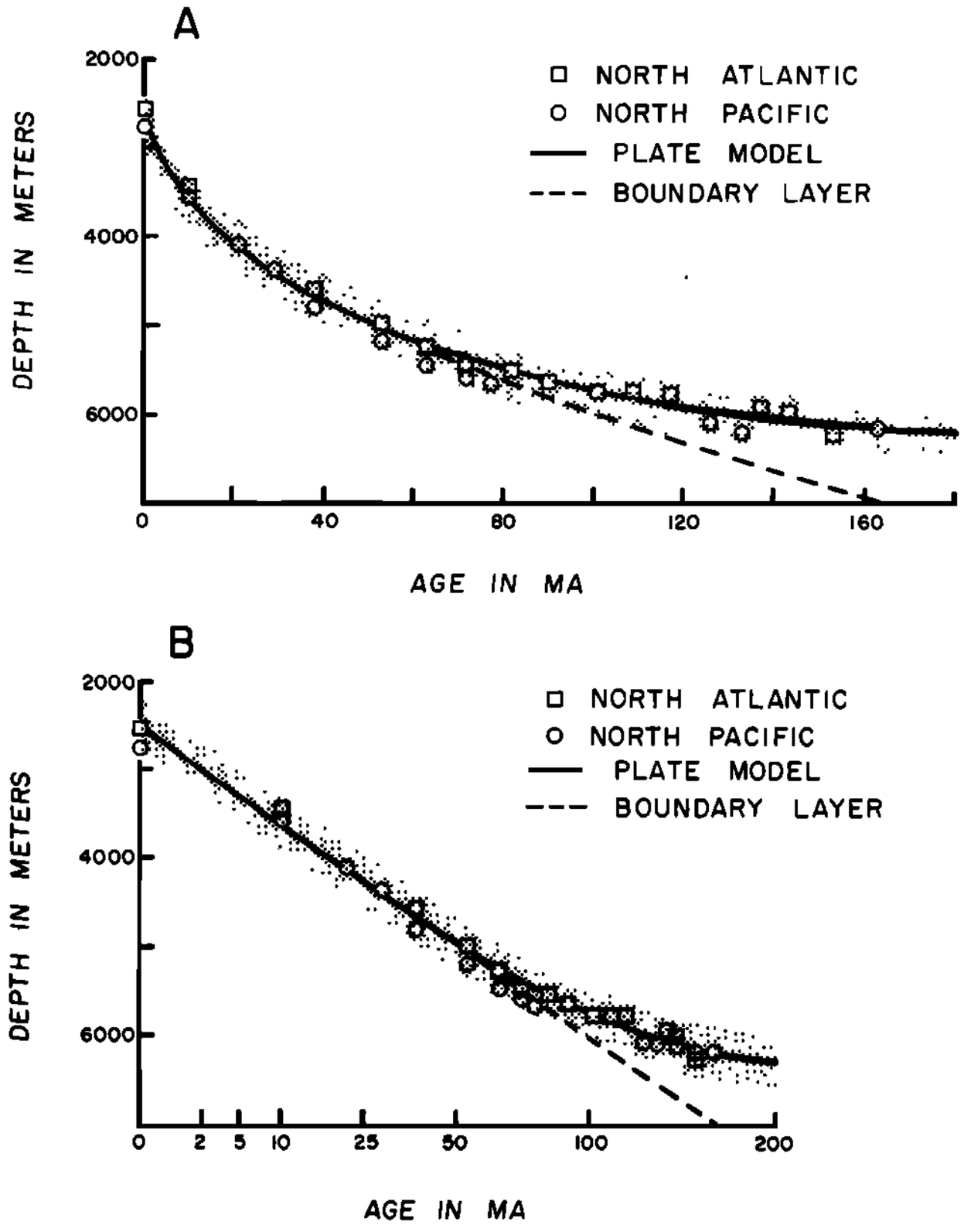
Sclater et al. 1980 Rev.Geophys.

Ocean depth vs. age



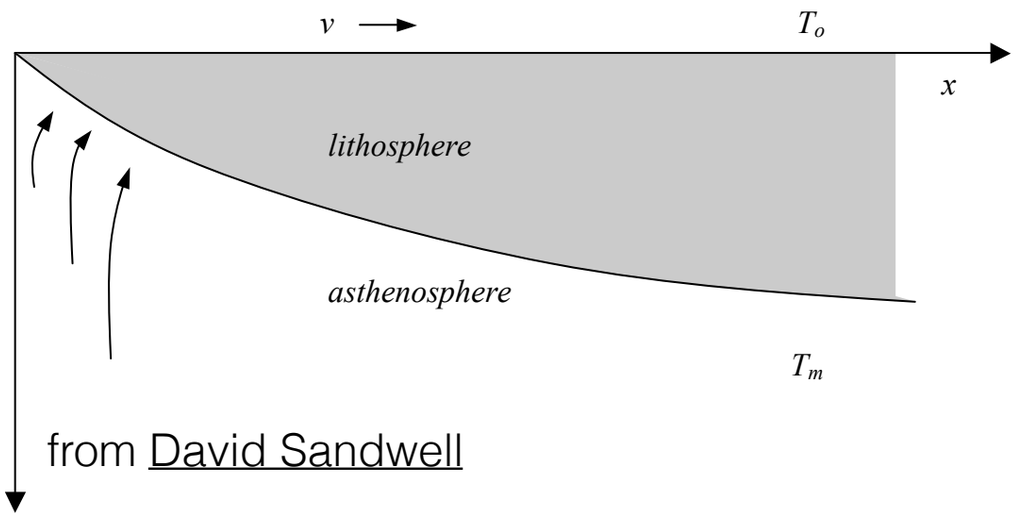
$$d_{tot}(t) = d_o + \frac{2\rho_m \alpha (T_m - T_o)}{(\rho_m - \rho_w)} \left(\frac{\kappa t}{\pi}\right)^{1/2}$$

Ocean depth vs. age



Sclater et al. 1980 Rev.Geophys.

Heat flow in oceanic areas



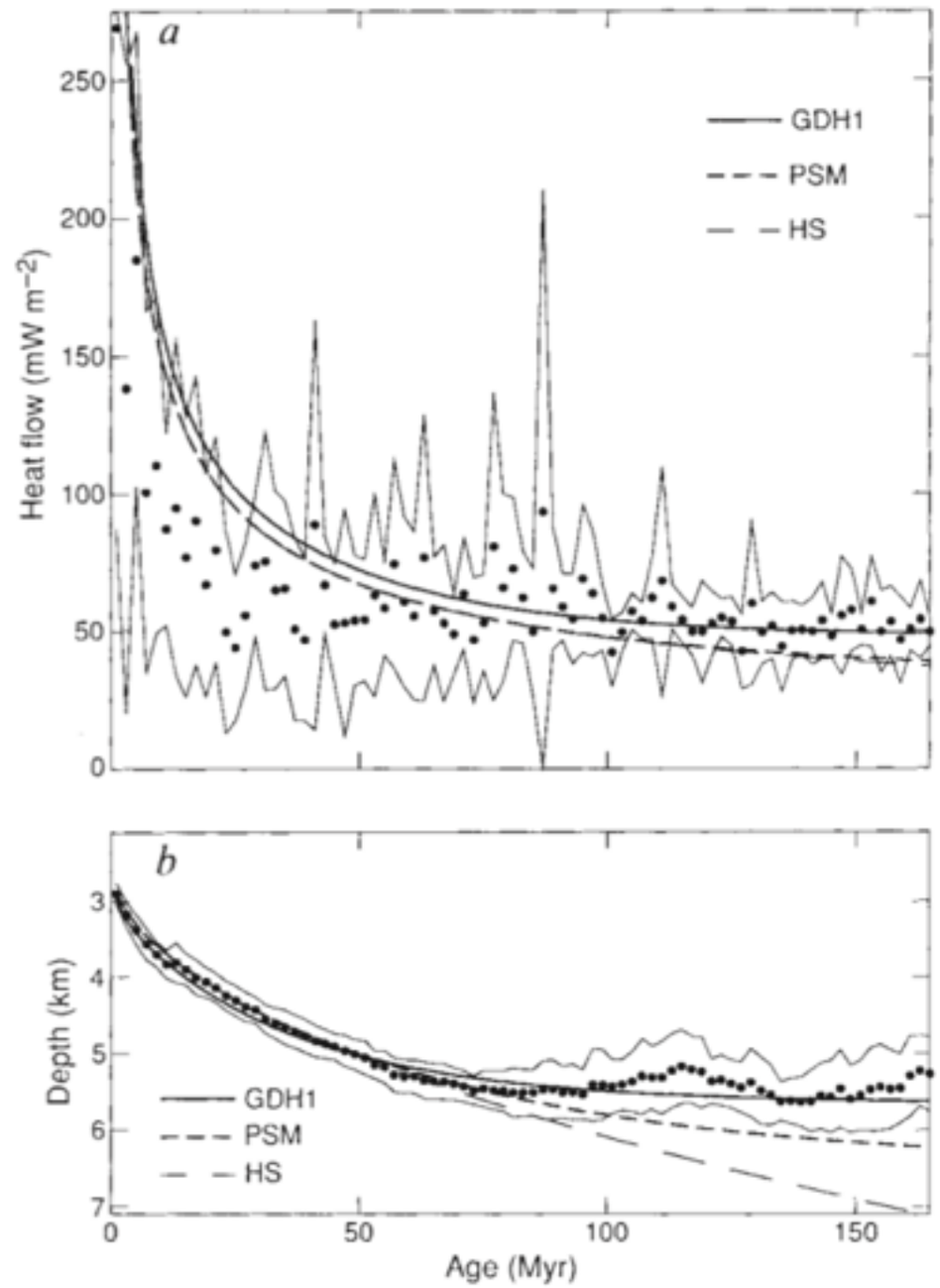
from David Sandwell

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2}$$

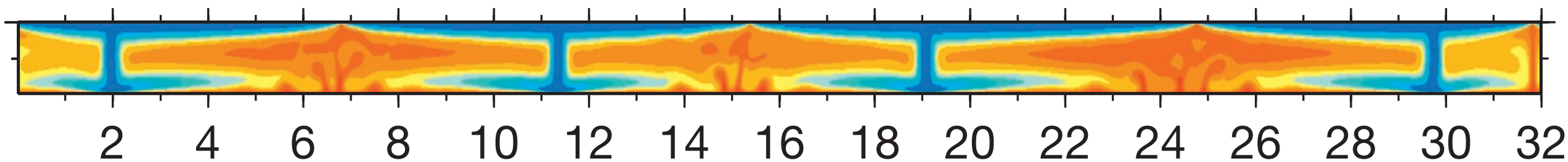
$$T = T_0 + (T_m - T_0)\mathrm{erf}\left(\frac{z}{\sqrt{4\kappa t}}\right)$$

heat flow $\propto (\kappa t)^{-1/2}$

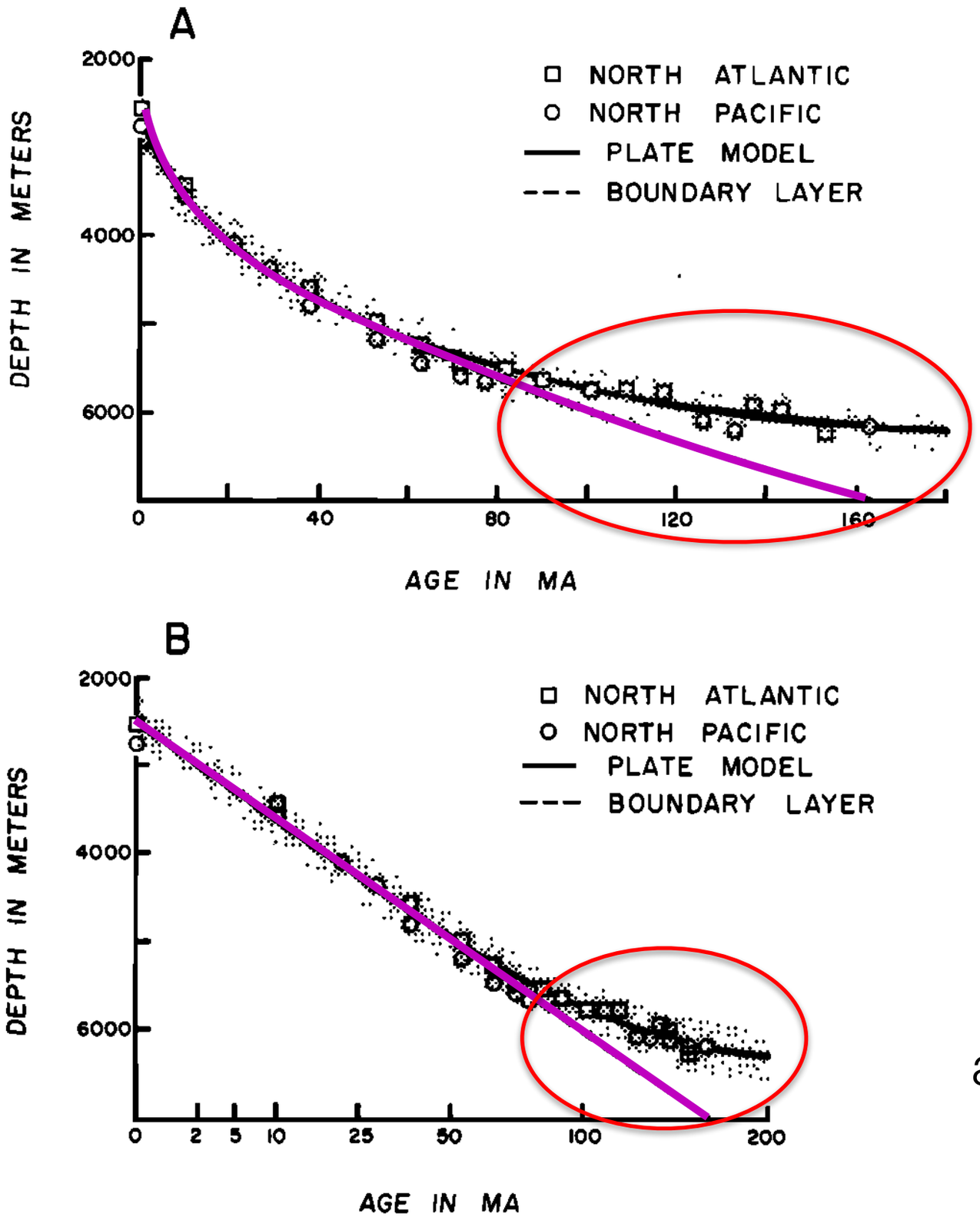
ocean depth $\propto (\kappa t)^{1/2}$



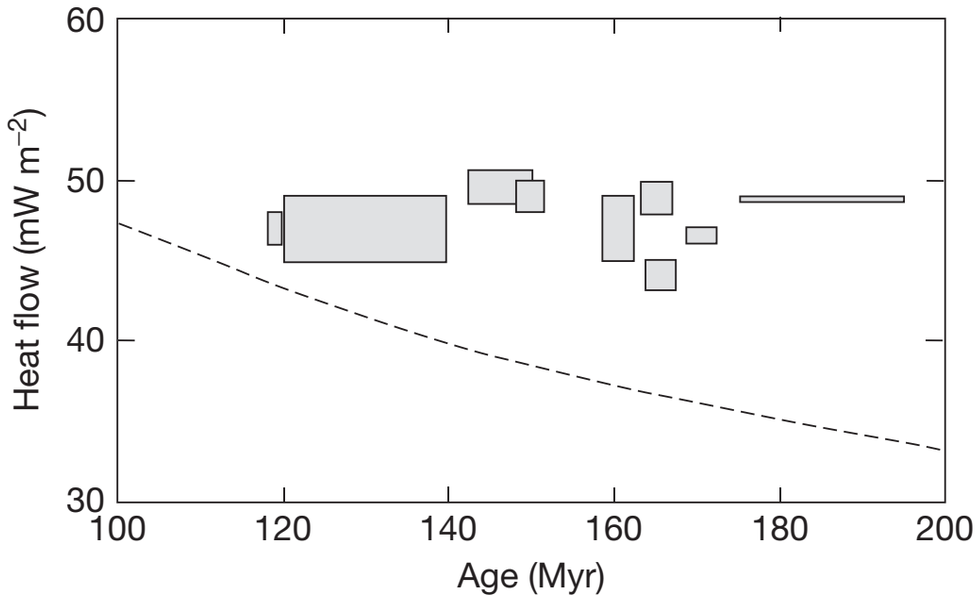
Stein & Stein 1992



Heat flow in oceanic areas



Sclater et al. 1980 Rev.Geophys.

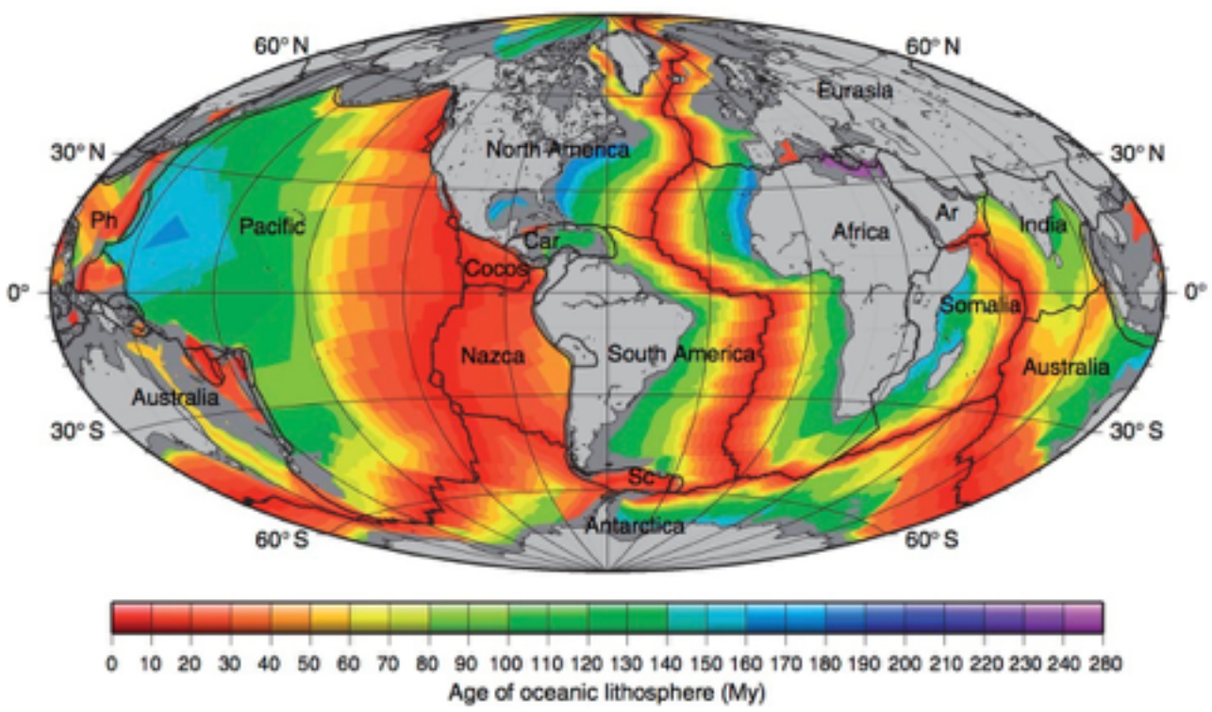


For ocean floor ages > 80 My, half-space cooling model deviates from measurements

Uniform heat-flux (48 mW/m^2) is a good approximation for > 80 My.

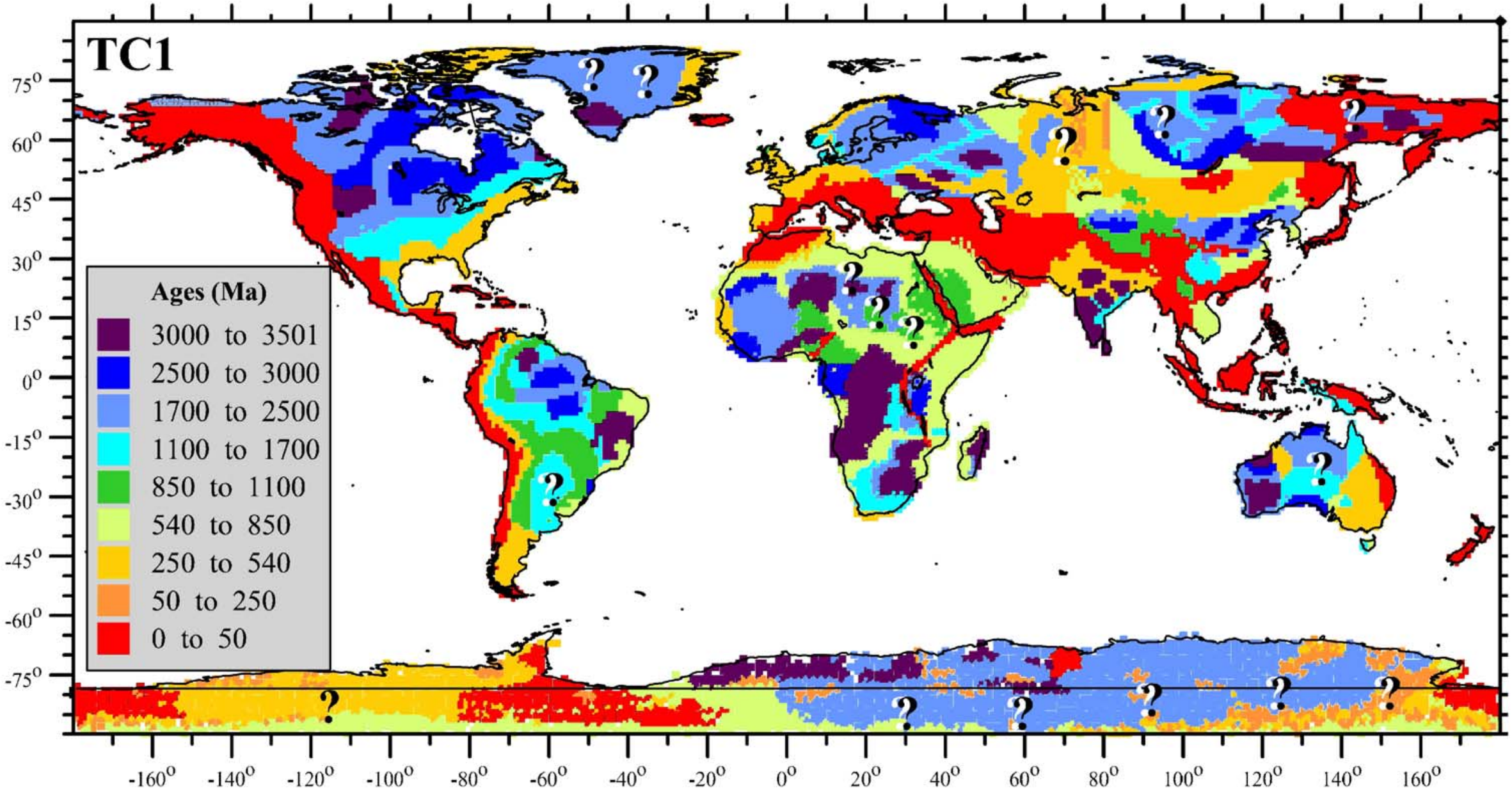
Heat flow in oceanic areas

Ocean floor age map + Half-space cooling model for ages < 80 My & Uniform heat flux for ages > 80 My



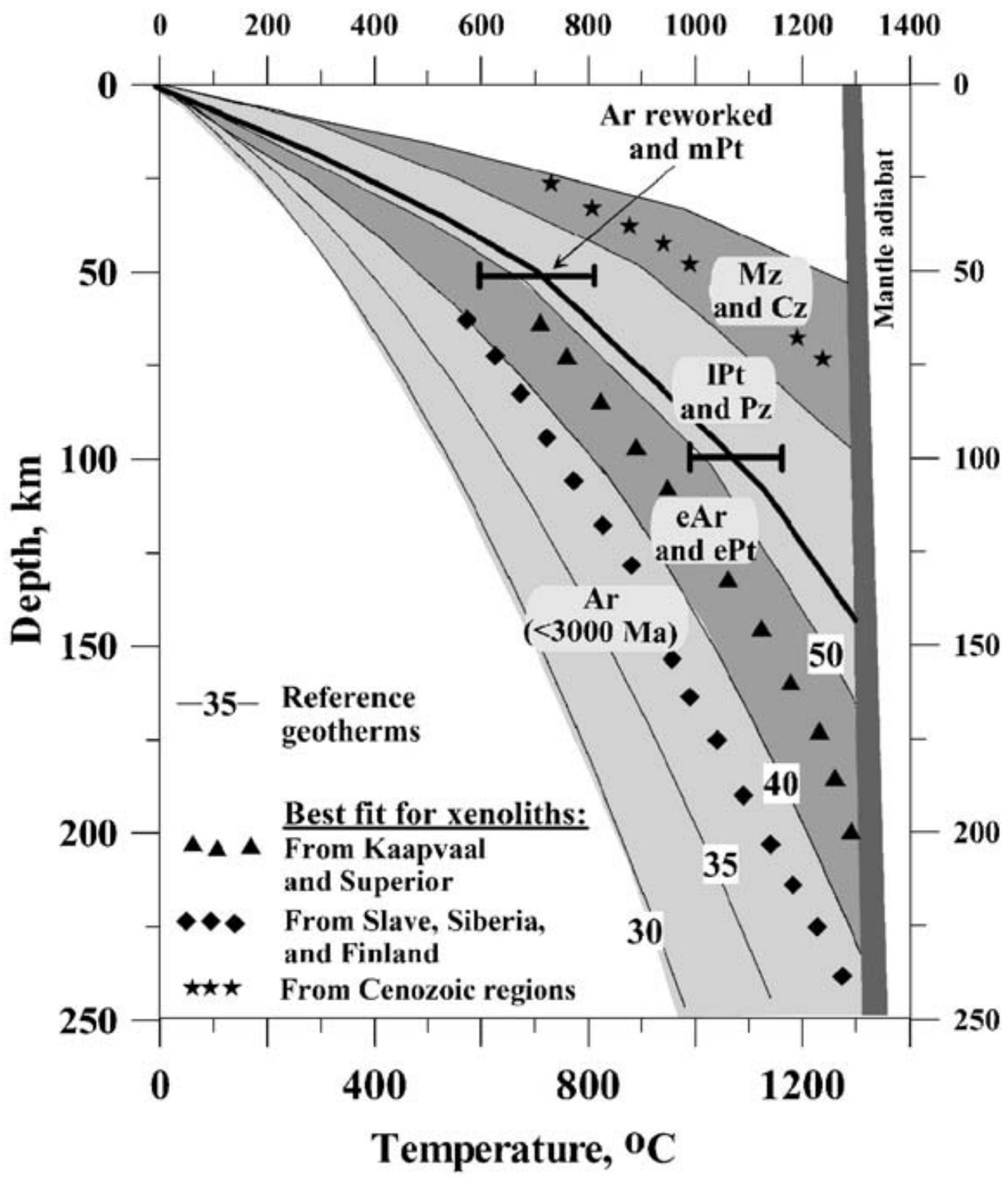
⇒ Integrate heat loss through oceans: 32 ± 2 TW

Tectonic ages of continents



Artemieva 2006

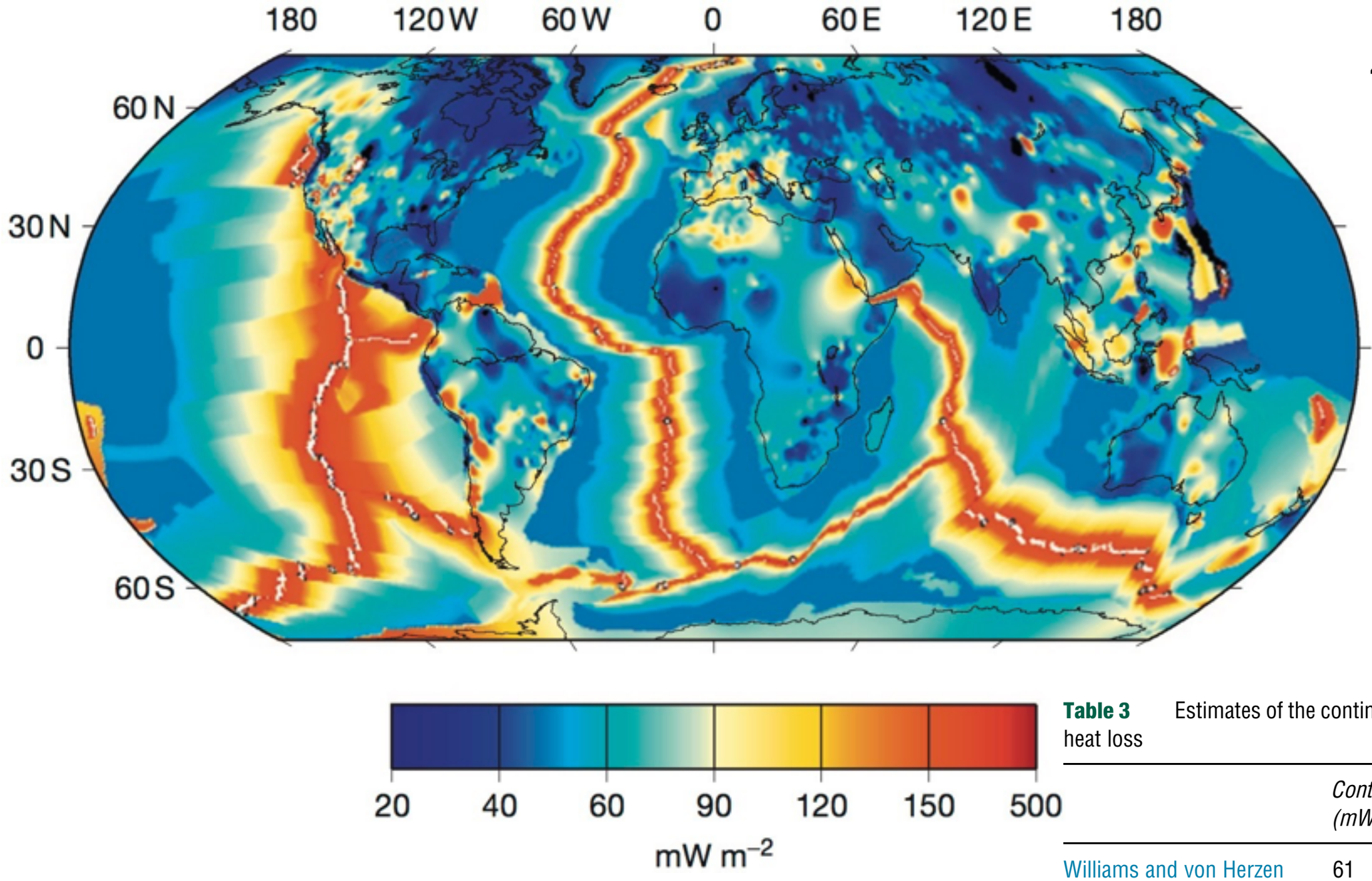
Continental geotherms



Artemieva 2006

Global surface heat loss

46 ± 3 TW



Jaupart et al. 2015 in Treatise on Geophysics

Table 3 Estimates of the continental and oceanic heat flux and global heat loss

	Continental (mW m^{-2})	*Oceanic (mW m^{-2})*	*Total (TW)*
Williams and von Herzen (1974)	61	93	43
Davies (1980a,b)	55	95	41
Sclater et al. (1980)	57	99	42
Pollack et al. (1993)	65	101	44
Davies and Davies (2010)	71	105	47
This study[a]	65	94	46

[a]The average oceanic heat flux does not include the contribution of hot spots. The total heat loss estimate does include 3 TW from oceanic hot spots.