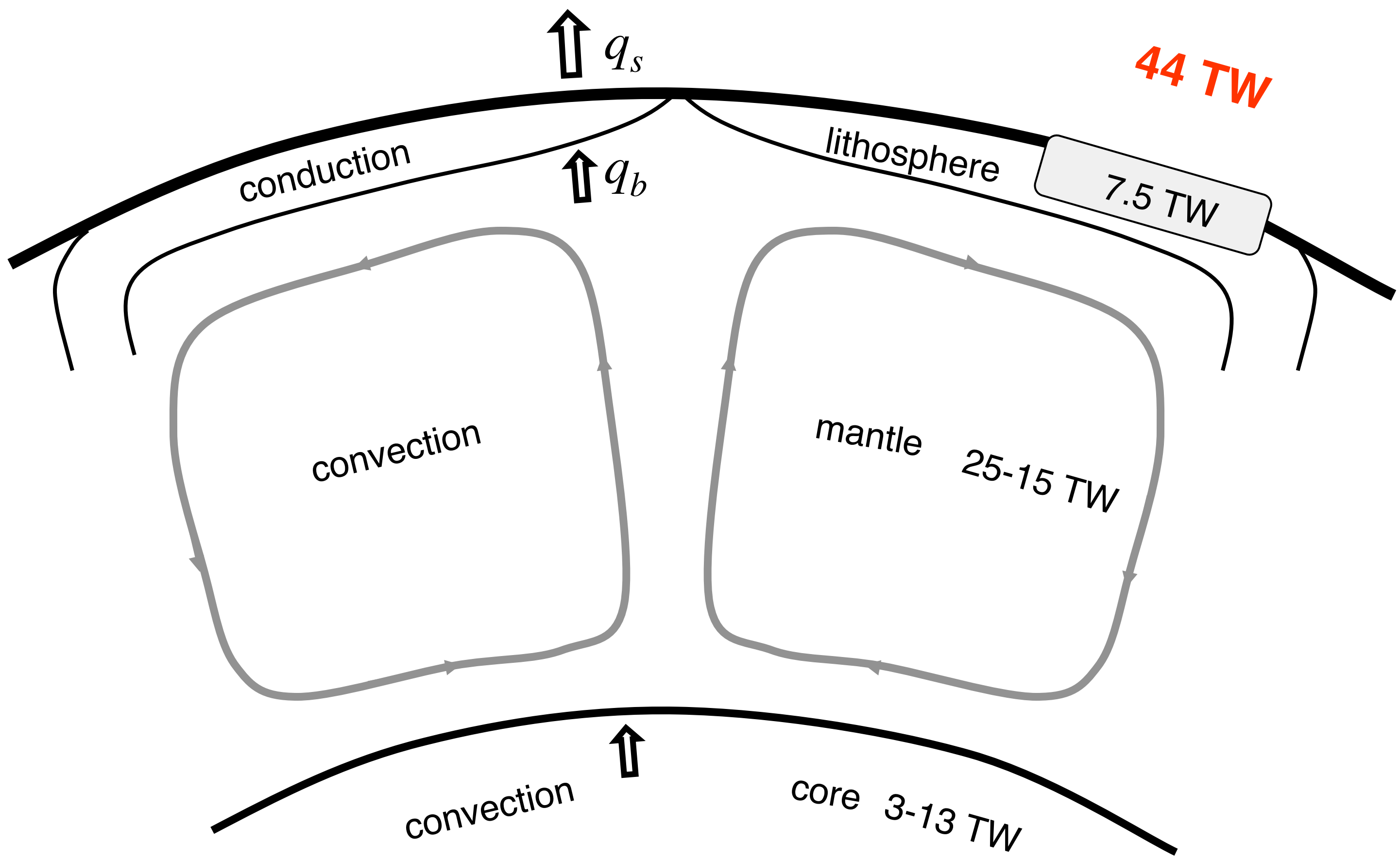
Lithospheric Heat Flow and Dynamics

- **obvious signals**
  - heat flow, depth, and geoid height versus age
  - does hydrothermal circulation really transport 10 TW?
- **inferred signals**
  - lithospheric thickness and strength versus age
  - swell-push force and global stress from the geoid
- **mysterious signals**
  - details of 3-D plate shrinkage
  - are gravity lineaments and volcanic ridges due to lithospheric shrinkage?
  - are transform faults thermal contraction cracks?

global heat budget

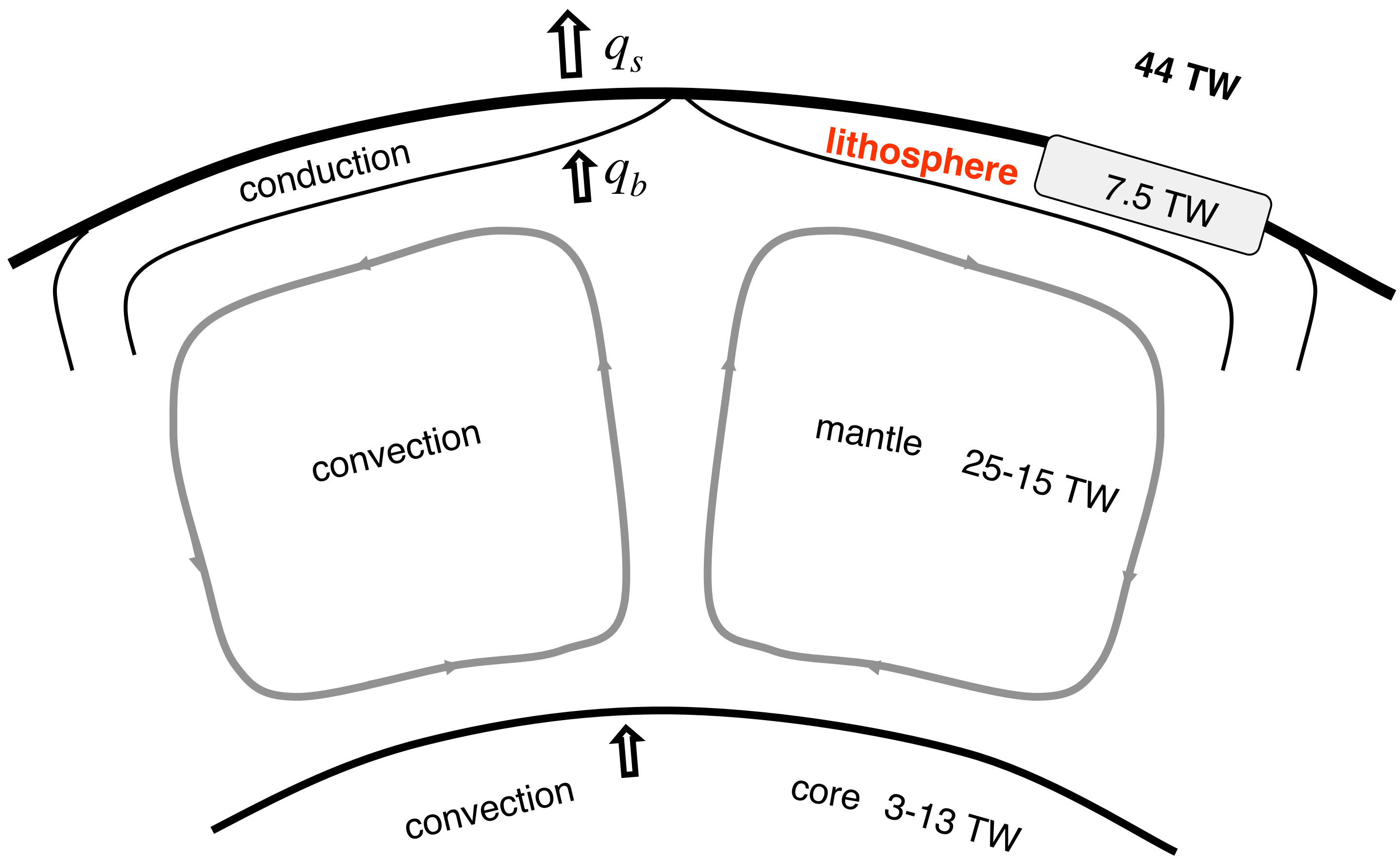


oceanic lithosphere dominates mantle convection

largest surface area

greatest temperature drop across TBL = largest density contrast

> 1/2 of heat escapes in young oceanic lithosphere



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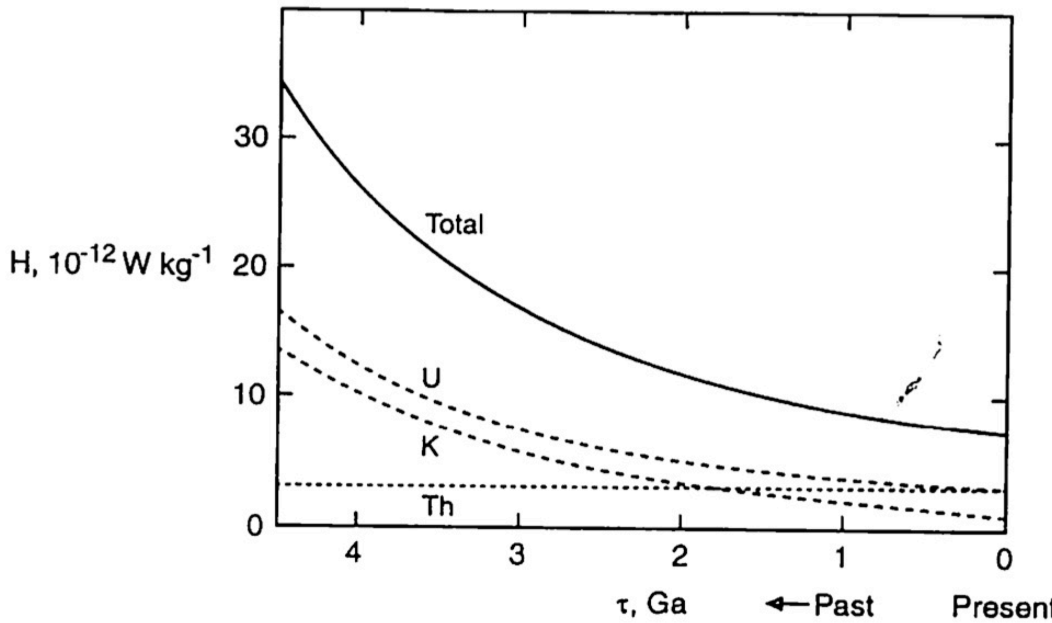


4–4 Mean mantle heat production rates due to the decay of the radioactive isotopes of U, Th, and K as functions of time measured back from the present.

plotted as a function of time before the present in Figure 4–4. The past contributions of the individual radioactive elements are also shown. We see that the rate of heat production 3×10^9 yr ago was about twice the

thermal expansion

volumetric expansion

$$\frac{\Delta V}{V} = \alpha \Delta T \qquad \text{or} \qquad \frac{\Delta \rho}{\rho} = -\alpha \Delta T$$

α - thermal expansion coefficient $\sim 3\text{x}10^{-5}\ {}^{\circ}C^{-1}$

linear expansion

$$\frac{\Delta l}{l} = \alpha_l \Delta T$$

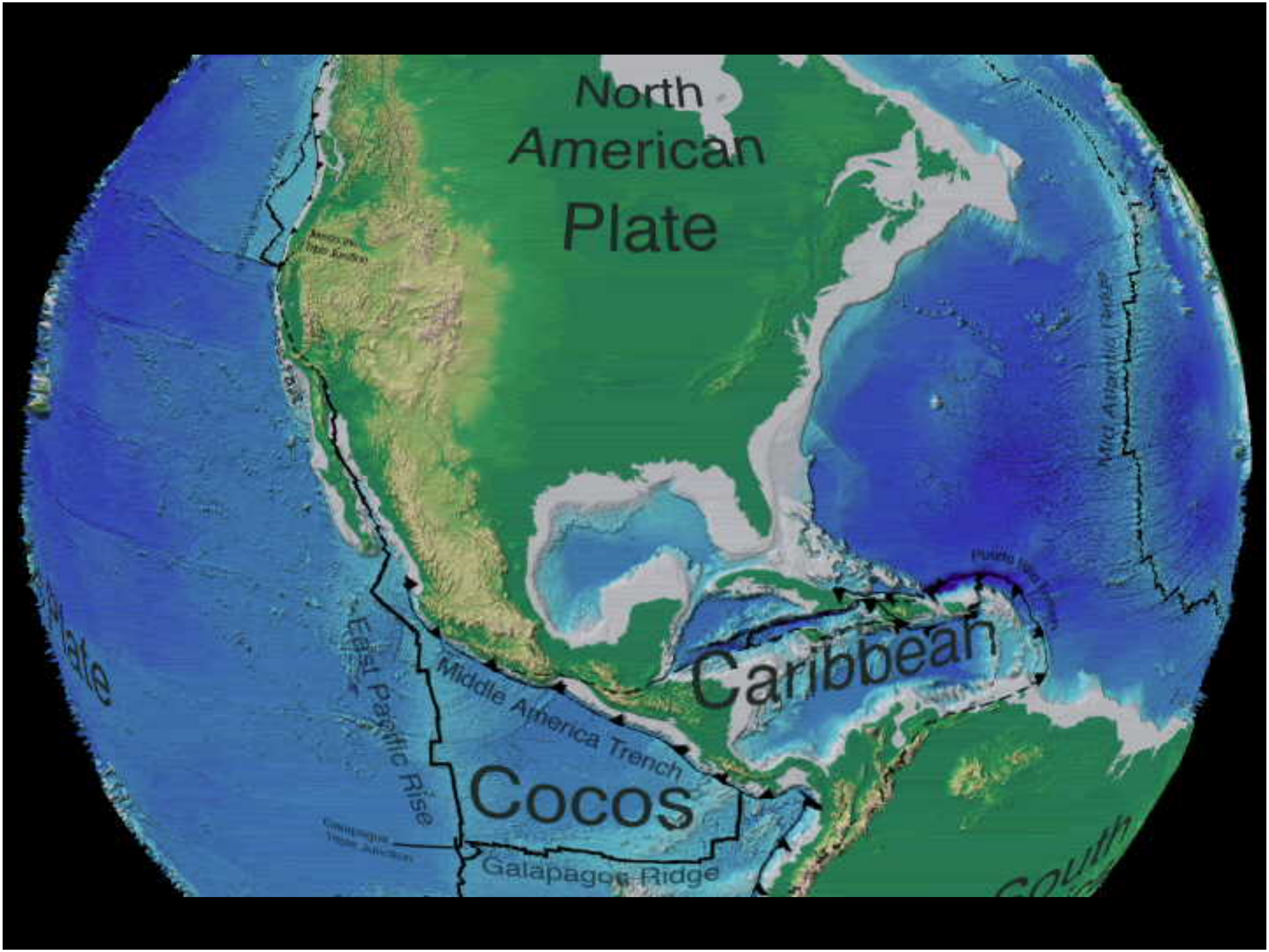
$$\alpha_l \cong \frac{\alpha}{3}$$

thermal stress develops when

$$\nabla(\Delta T) \neq 0$$

obvious signals

- depth versus age
- heat flow versus age
- geoid height versus age


North American Plate
Caribbean
Cocos
Middle America Trench
East Pacific Rise
Galapagos Ridge
Mid Atlantic Ridge
South

depth vs age ➡ $d(t) = \frac{-\alpha\rho_m}{\rho_m - \rho_w} \int_0^L T dz$ ➡ $d(t) \cong 2500 + 350 t^{1/2}$

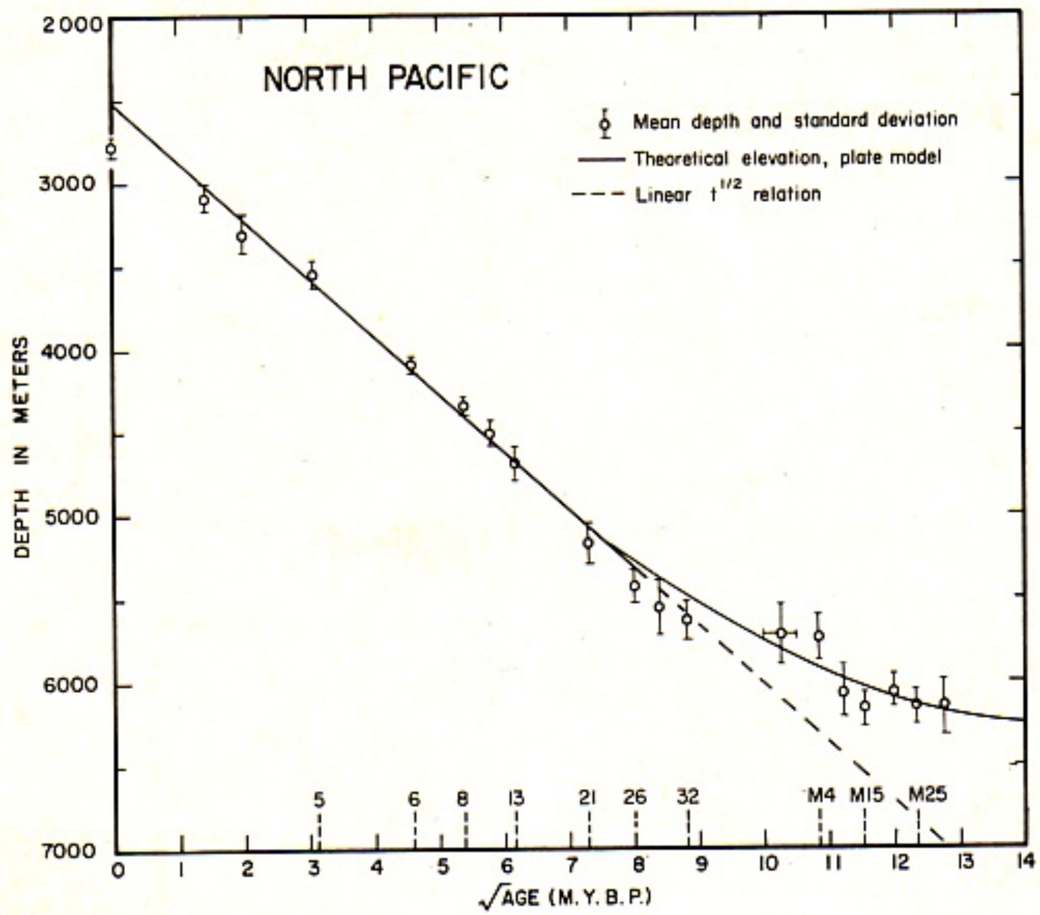
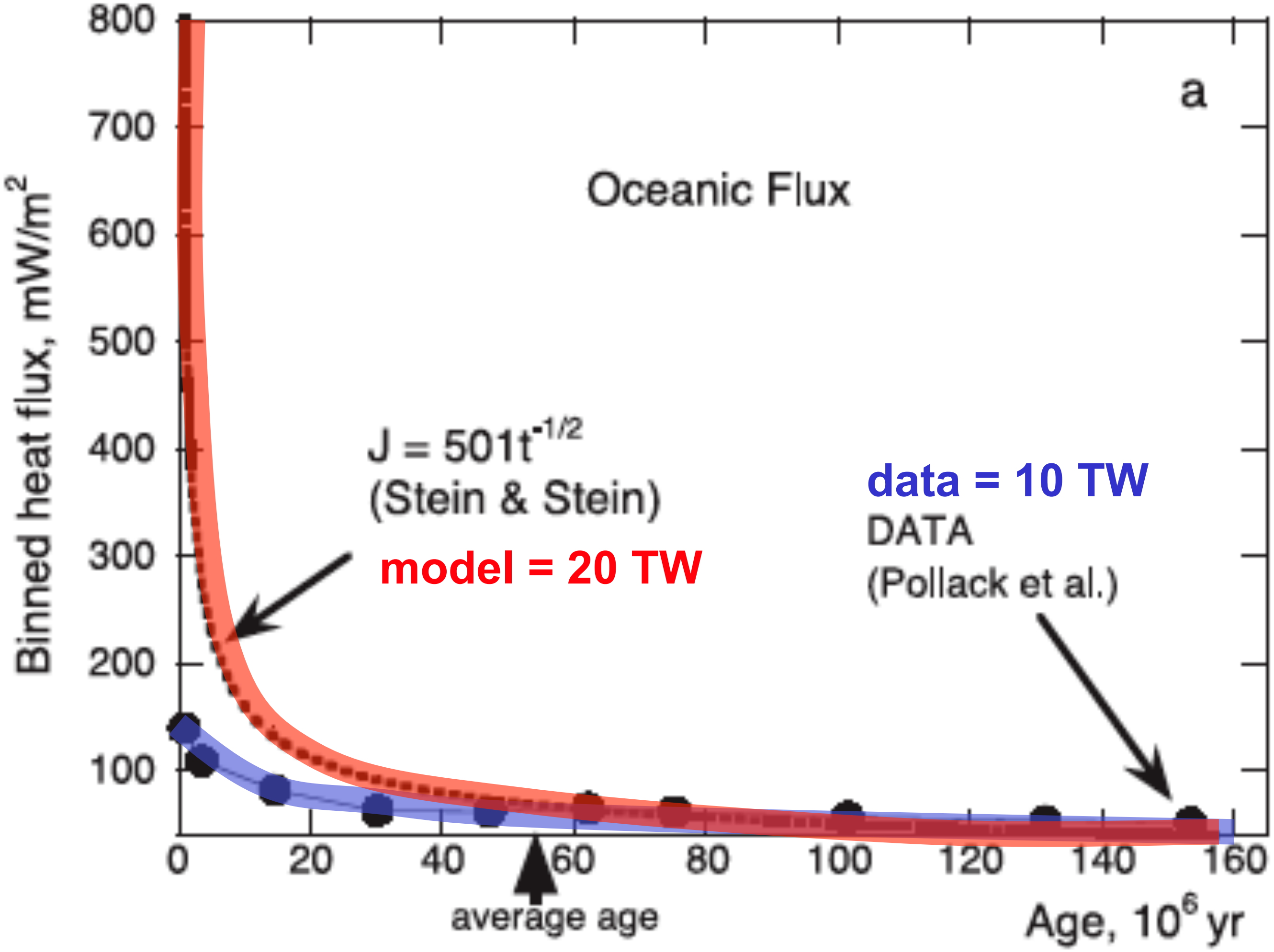


Fig. 1. Plot of mean depth in the North Pacific versus the square root of age. Numbers at the bottom of the figure denote selected Cenozoic and Mesozoic magnetic anomalies [from *Parsons and Sclater*, 1977].

heat flow vs age ➡ $q(t) = k\dfrac{\partial T}{\partial z}$ ➡ $q(t) \cong 480\,t^{-1/2}$

A.M. Hofmeister, R.E. Criss / Tectonophysics 395 (2005) 159–177



What is the global heat output of the Earth?

How do we interpret this discrepancy?

A) The other 10 TW is transferred by hydrothermal circulation [*Lister*, 1972; *Williams et al.,* 1974; *Sleep and Wolery*, 1978, *Anderson and Hobart*, 1976; *Stein,* 1995]

B) The other 10 TW does not exist and the total heat output from the Earth is $<$ 34 TW [*Hofmeister and Criss*, 2005].

conservation of energy

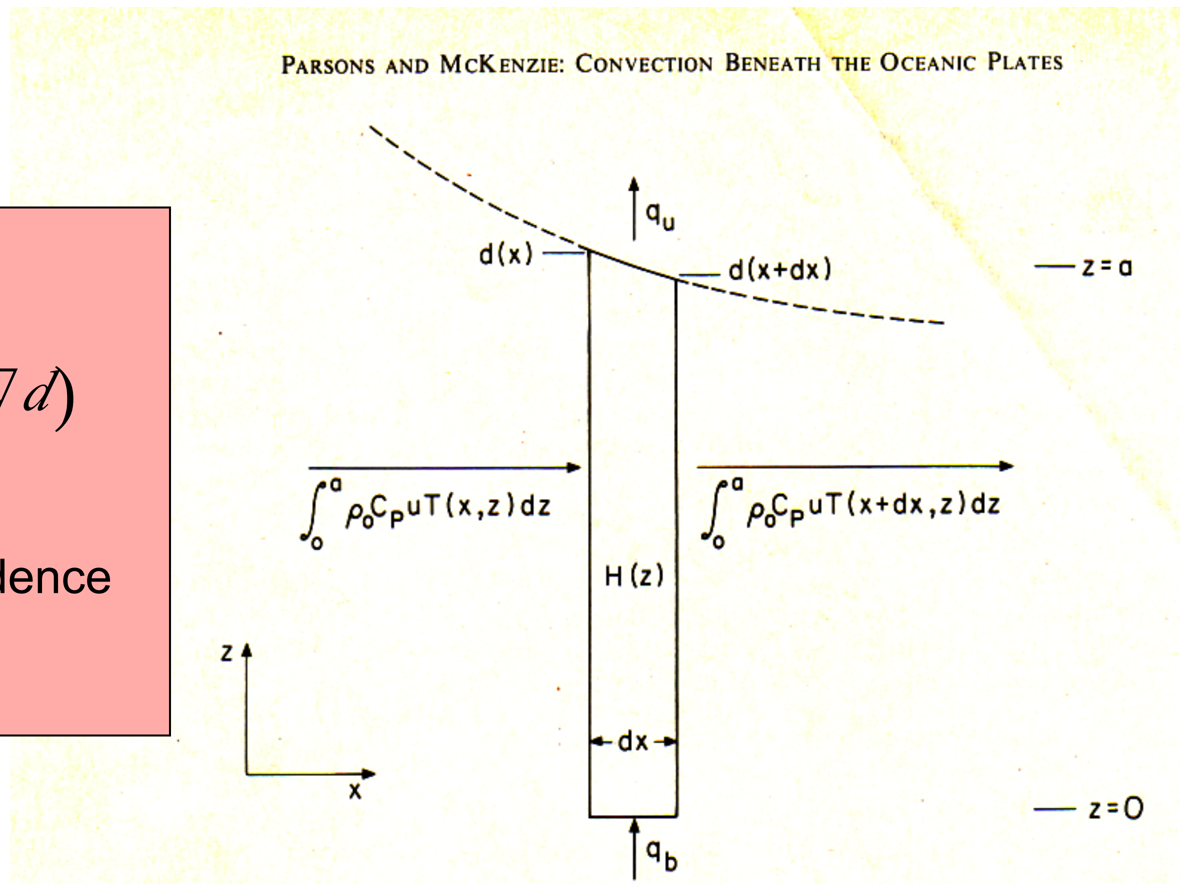
$$\rho_m C_P \mathbf{v} \bullet \nabla T = \nabla \bullet \mathbf{q}$$

thermal isostasy

$$d(t) = \frac{-\alpha\rho_m}{\rho_m - \rho_w} \int_0^L T dz$$

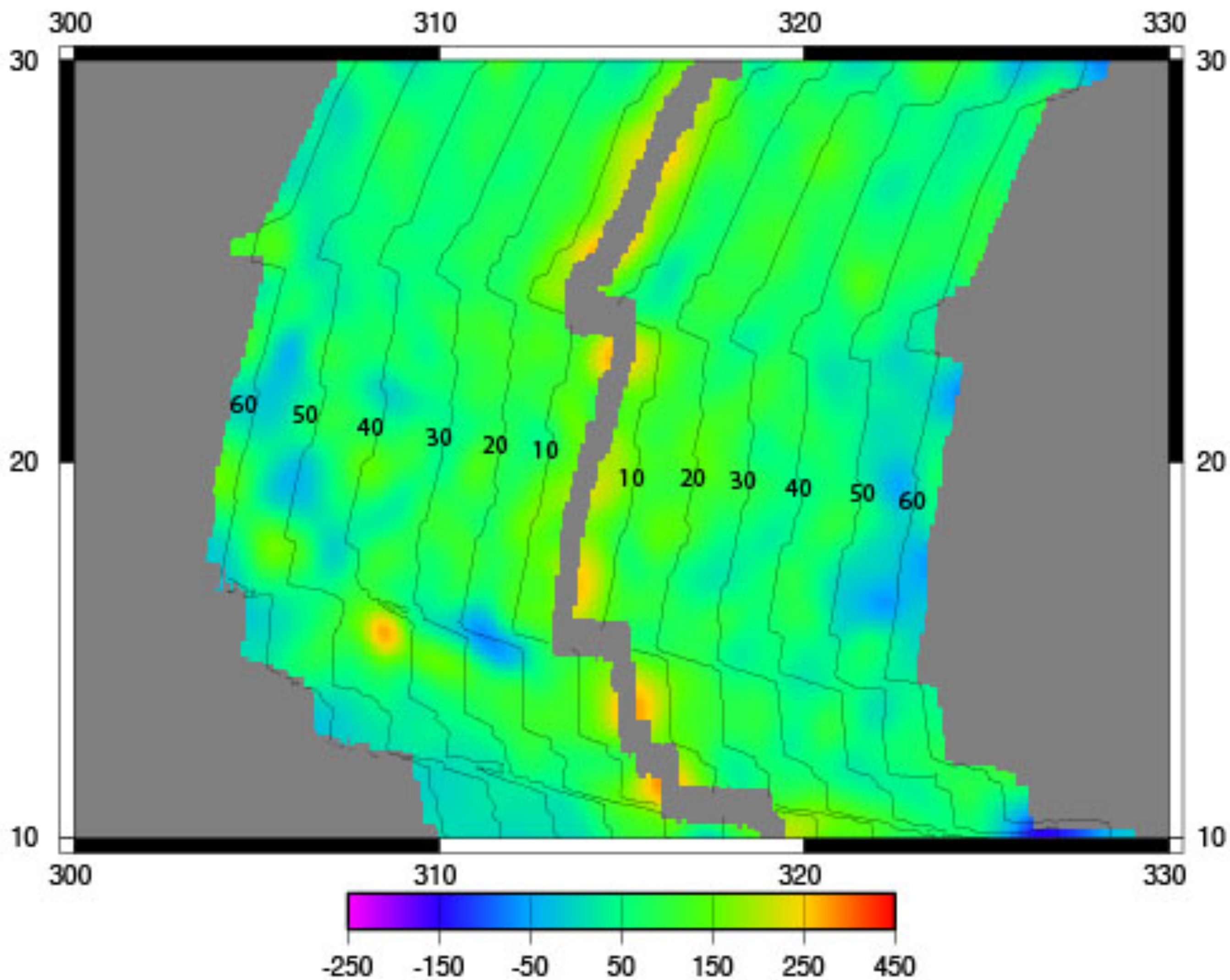
$$(q_b - q_u) = \frac{(\rho_m - \rho_w) C_p}{\alpha} (\mathbf{v} \bullet \nabla d)$$

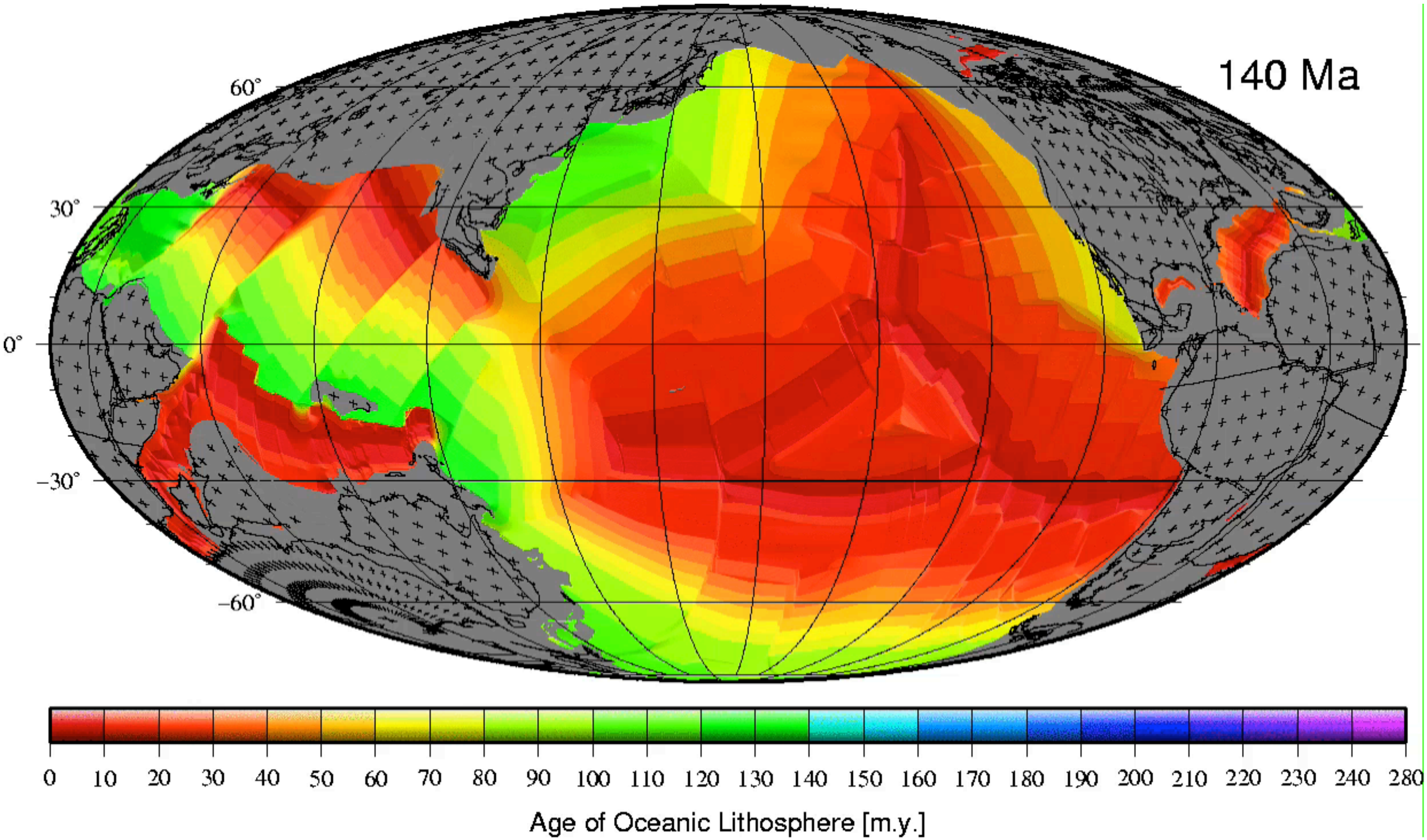
heat flow = constant X scalar subsidence rate



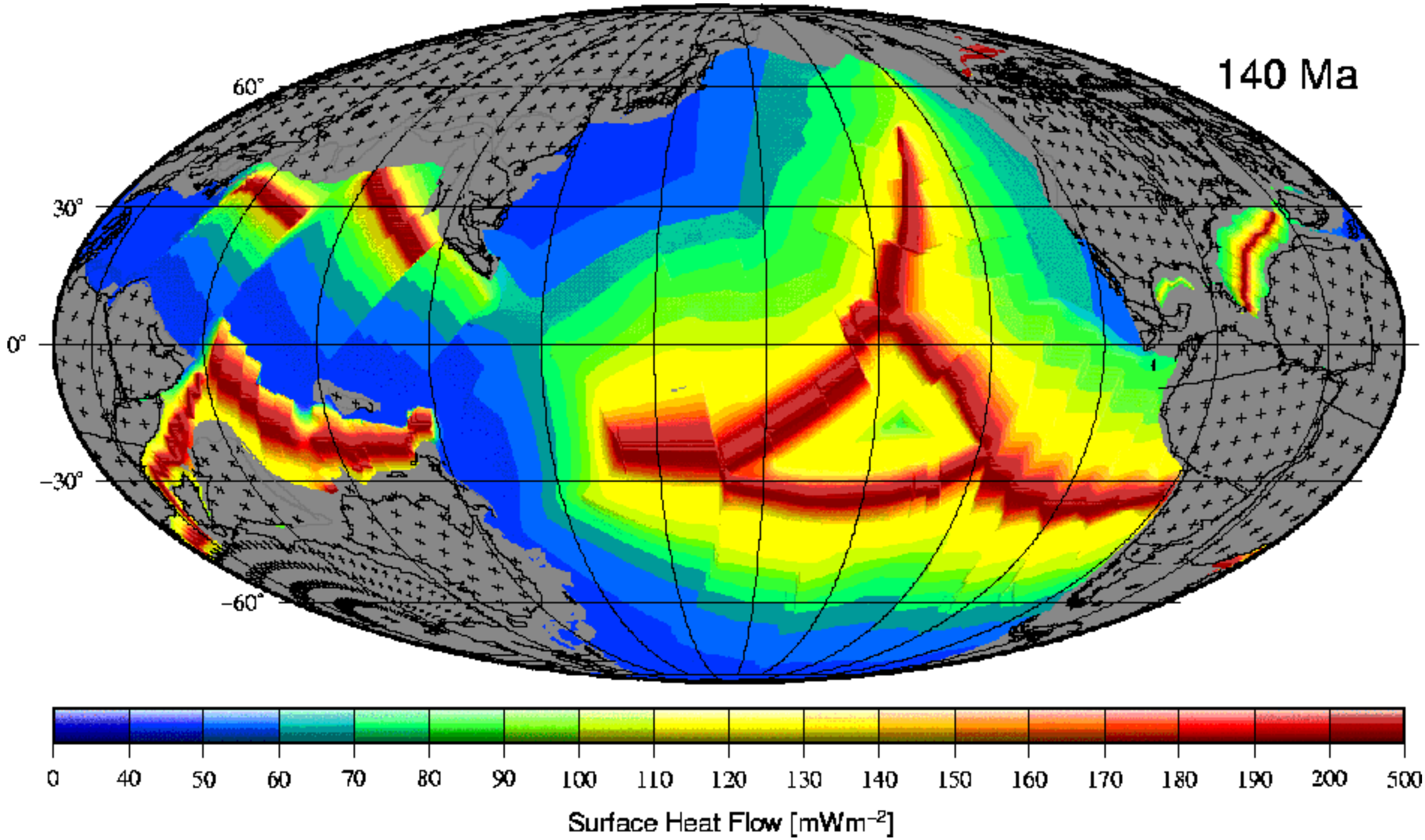
heat flow related to subsidence rate

$$(q_b - q_u) = \frac{(\rho_m - \rho_w)C_p}{\alpha}\frac{\nabla A \bullet \nabla d}{\nabla A \bullet \nabla A}$$





Mueller, personal communication 2006



Mueller, personal communication 2006

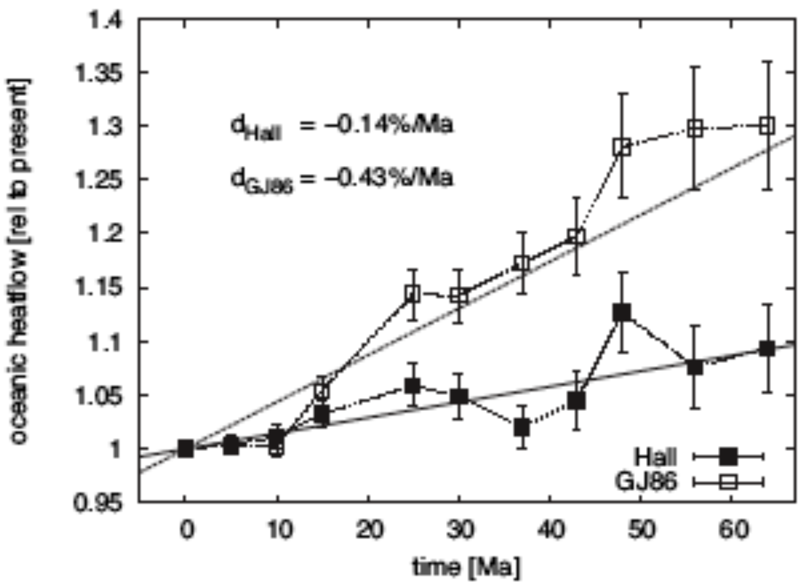


Fig. 2. Temporal variation of the globally integrated heat flow based on the estimates from the two plate tectonic reconstructions as shown in Fig. 1. For regions with half-space cooling-derived heat flow ($q = C_A t^{-1/2}$), we performed an integration over seafloor age by summing over 1-Myr age integrals and multiplying each of these integrals by the area of seafloor within that age interval. Error bars for each heat flow estimate are computed by assuming progressively increasing uncertainty in these area estimates as described below. Filled square symbols (Hall) are for Xu *et al.*'s (6) reconstruction based on Hall (34), and open squares (GJ86) are based on Gordon and Jurdy (33). Solid and dashed lines are best-fit linear trends with rates, *d*, of relative change in total oceanic heat flow specified in the key.

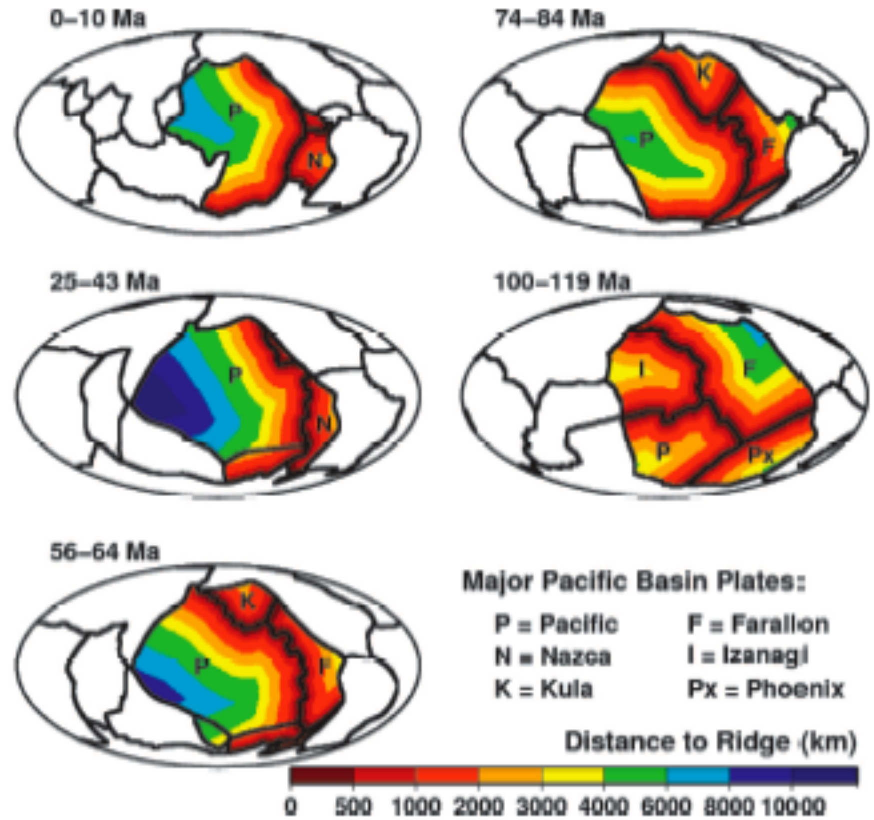


Fig. 3. Cenozoic and Mesozoic evolution of the Pacific basin as characterized by seafloor distance to the nearest mid-ocean ridge. Notice the progression from four relatively small plates to one large plate and compare with Fig. 1. Maps were created after Lithgow-Bertelloni and Richards (39).

Loyd, Becker, Conrad, Litho-Bertelloni and Corsetti, PNAS, 2007

obvious signals - summary

heat flow versus age

$$q_s(t) = k\frac{\partial T}{\partial z}$$

- surface temperature gradient
- noisy, observations << model

depth versus age

$$d(t) = \frac{-\rho_m}{\rho_m - \rho_w}\int_0^L \alpha T dz$$

- integrated temperature
- **observations = model**

geoid height versus age

$$N(t) = \frac{-2\pi G\rho_m}{g}\int_0^L \alpha T z dz$$

- first moment of temperature
- dominated by mantle geoid, observations ~ model

Inferred signals

- lithospheric strength versus age (see *Watts*, 2001)
- swell-push force and global stress from the geoid

Hawaiian-Emperor seamount chain

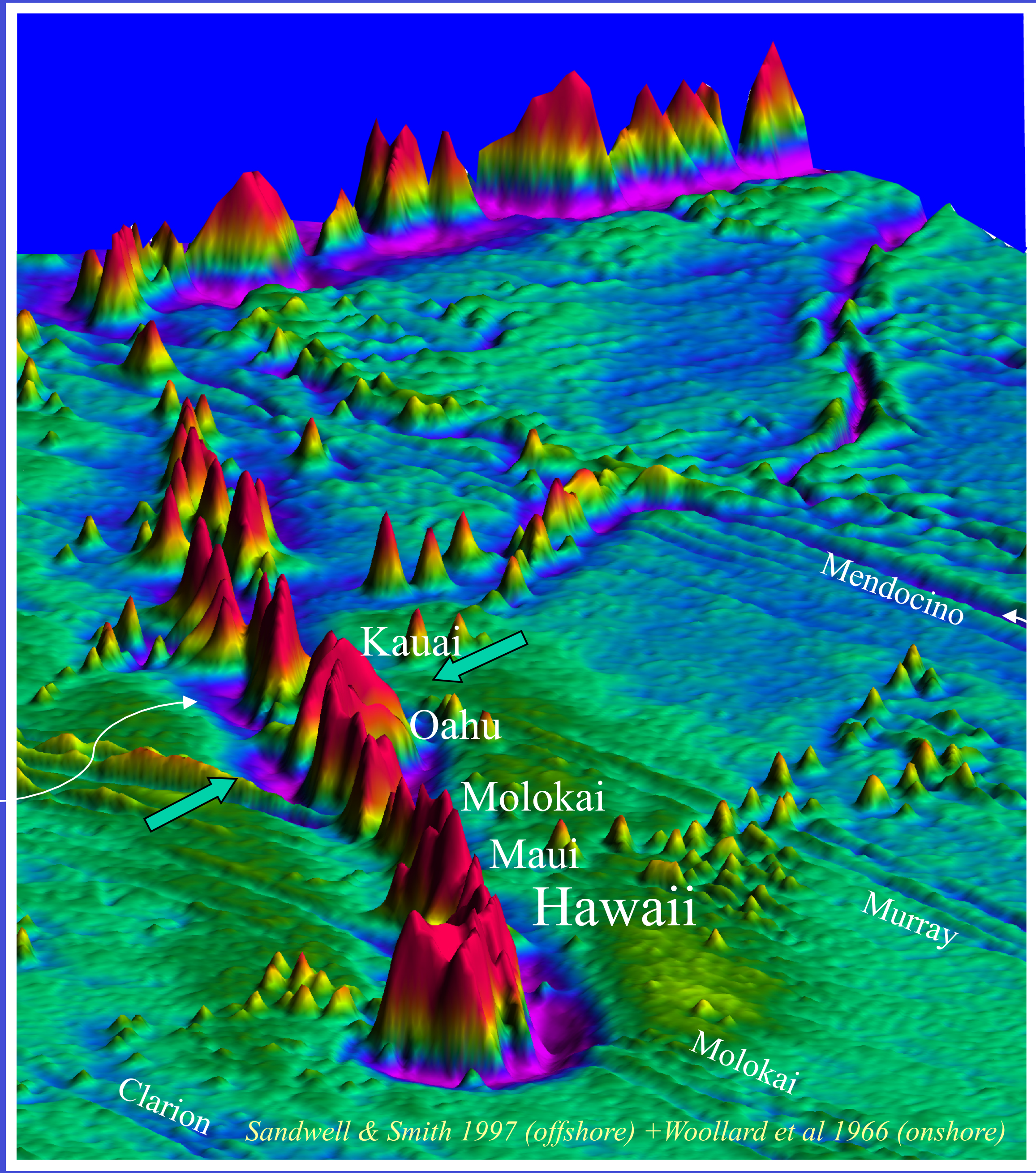
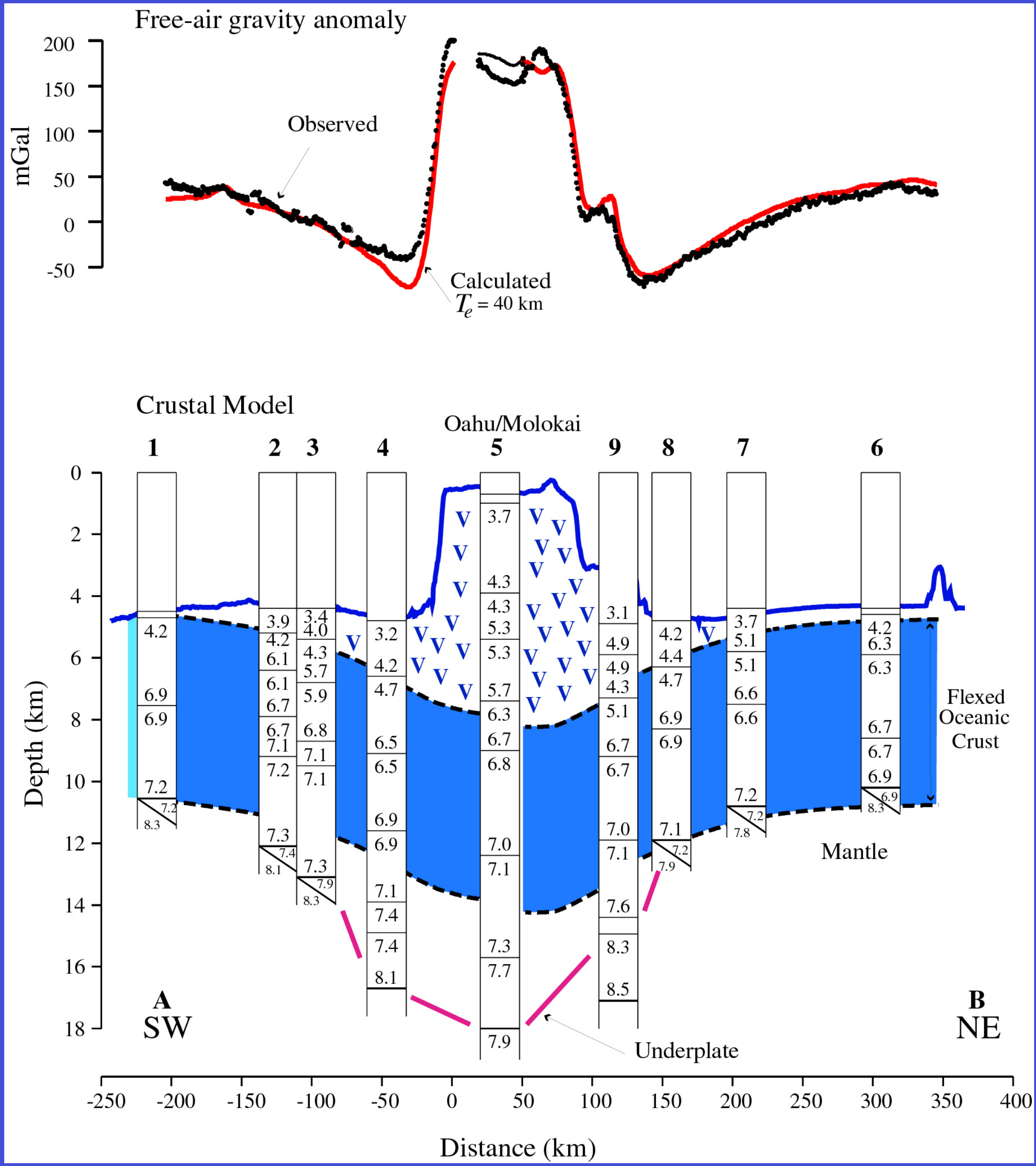


Plate Mechanics (flexure)

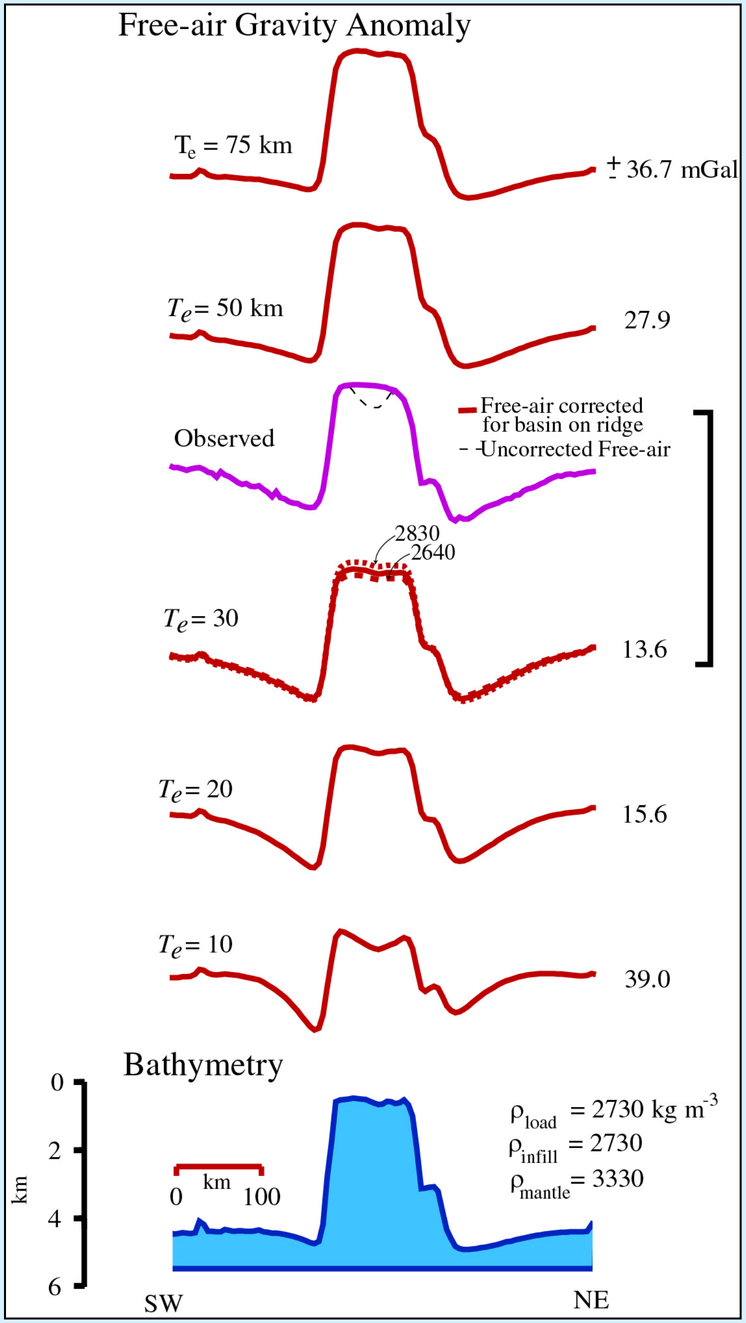
Plate kinematics

Gravity anomalies and crustal structure at Oahu/Molokai

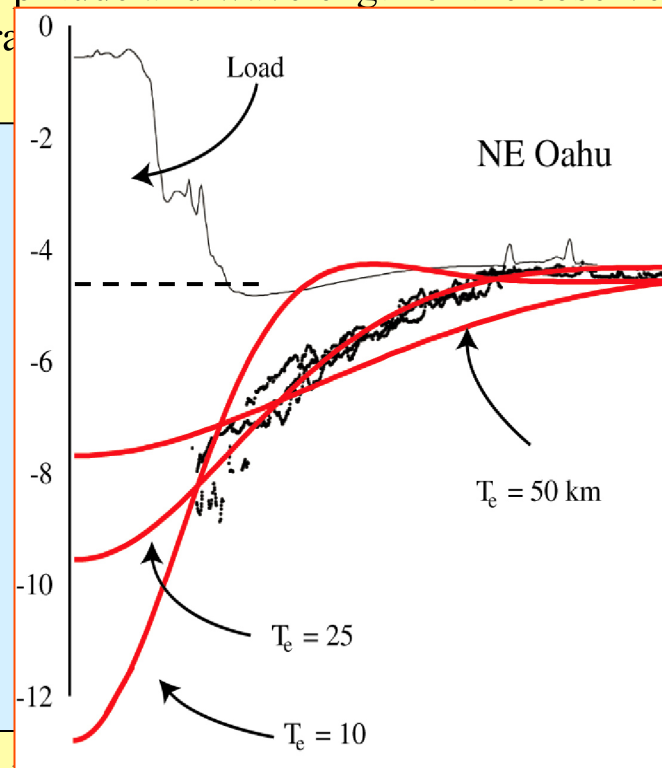


Watts & ten Brink (1989)

Estimating T_e

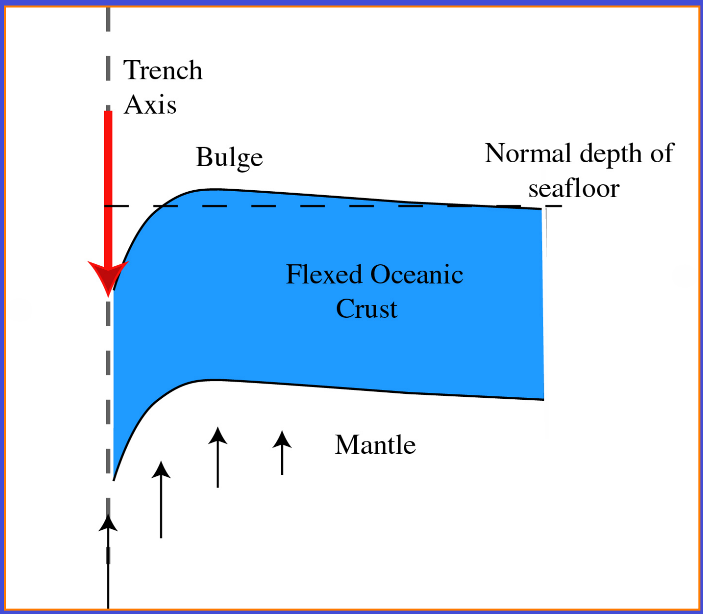


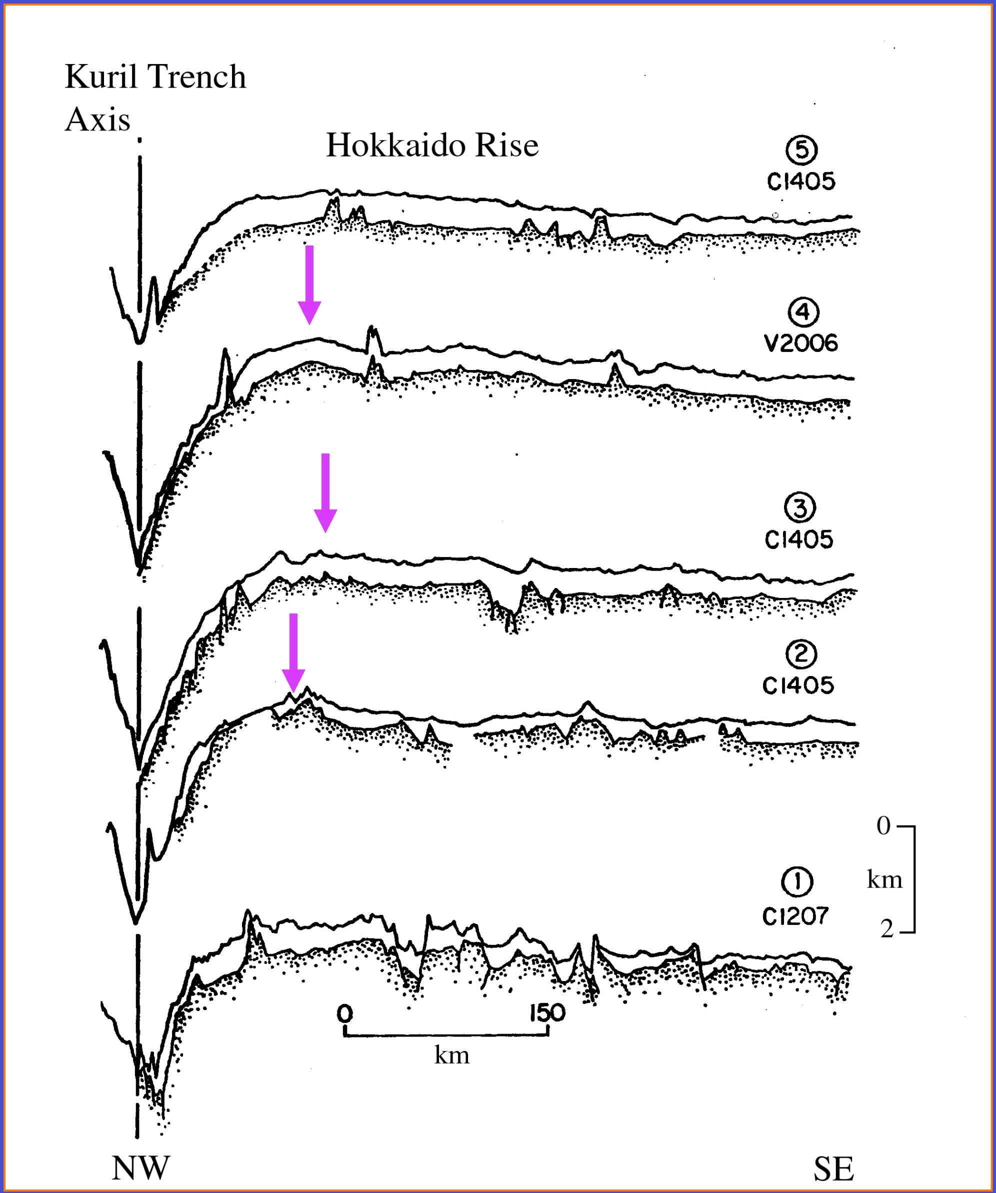
T_e can be estimated by comparing the amplitude and wavelength of the observed gra



The ... een observed and calculated gravity anomaly indicate a 'best fit' T_e ~ 30 km.

Topography seaward of the Kuril Trench

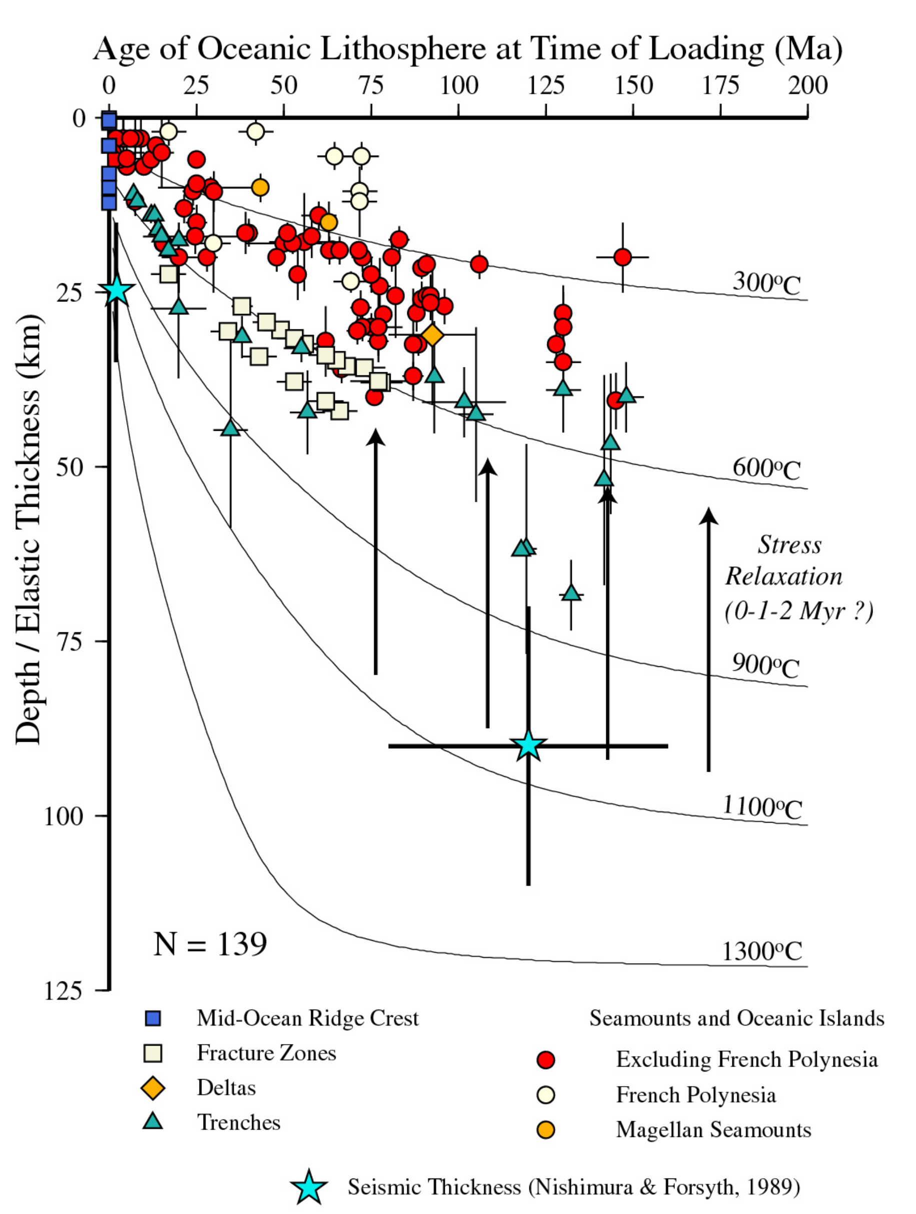




Distance to bulge ~ 120-140 km

T_e ~ 30 km

Relationship between oceanic T_e and plate and load age



Watts & Zhong (2000)

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