Global Oceanic Heat Flow

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Um, don’t we go over this in every geophysics class ever?

• Classic problem considers change in depth/age and heat flow across a line perpendicular to the ridge axis

• With this problem, we are looking at an equation for heat flow of the ocean floor in two dimensions
Goal

Derive an expression relating the depth and age of the seafloor to the local heat flow
WHY?

Heat flow measurements are difficult and there is no practical way to have a high density of measurements over the entire ocean basins.

By finding an expression relating the depth and age to $q_s$, heat flow can be estimated without actually taking a heat flow measurement.

This approach uses bathymetry data combined with an age grid of the sea floor to find $q_s$. 
Assumptions

- Steady state spreading
- Oceanic crust with NO internal heat production
- Lateral heat transport is negligible
Governing equations:

Conservation of energy

\[ \rho_m C_p \mathbf{v} \cdot \nabla T = \nabla \cdot \mathbf{q} \]

Density as a function of temperature

\[ \rho(T) = \rho_m \left[ 1 - \alpha (T - T_m) \right] \]

Depth as a function of integrated temperature

\[ d(t) = \frac{-\alpha \rho_m}{\rho_m - \rho_w} \int_{d}^{L} (T - T_m) \, dz \]
First, take gradient of each side of depth function then dot product with $\mathbf{v}$

$$\mathbf{v} \cdot \nabla d(t) = \frac{-\alpha \rho_m}{\rho_m - \rho_w} \int_d^L \mathbf{v} \cdot \nabla T \, dz$$

Then plug in for $\nabla \cdot \mathbf{q}$ from conservation of energy

$$\mathbf{v} \cdot \nabla T = \frac{1}{\rho_m C_p} \mathbf{v} \cdot \mathbf{q}$$

$$\mathbf{v} \cdot \nabla d(t) = \frac{-\alpha}{(\rho_m - \rho_w) C_p} \int_d^L \nabla \cdot \mathbf{q} \, dz$$
Then, implement assumption of no lateral heat transport

\[ \int_{d}^{L} \nabla \cdot \mathbf{q} dz \]

Becomes…..

\[ \int_{d}^{L} \frac{\partial}{\partial z} q(z) dz = q(L) - q(d) = q_\infty - q_s \]

\[ \mathbf{v} \cdot \nabla d(t) = \frac{-\alpha}{(\rho_m - \rho_w)C_p} (q_\infty - q_s) \]
Then, working with a grid of sea floor ages, need to find velocity (measured perpendicular to spreading ridge).
Velocity vector is:

\[ \mathbf{v} = \frac{\nabla A}{\nabla A \cdot \nabla A} \]

Finally, substituting \( \mathbf{v} \) into equation, we get

\[ \frac{\nabla d \cdot \nabla A}{\nabla A \cdot \nabla A} = \frac{-\alpha}{(\rho_m - \rho_w)C_p} (q_\infty - q_s) \]
End result:

\[ q_s = \frac{(\rho_m - \rho_w)C_p}{\alpha} \frac{\nabla d \cdot \nabla A}{\nabla A \cdot \nabla A} + q_\infty \]

\( q_s \) is determined from topography and age data and is dependent upon heat capacity and the coefficient of thermal expansion
Limitations

• Not taking into account sediment load or subsequent compensation
• Not taking into account seamounts
• Need to have good values for coefficient of thermal expansion as well as heat capacity
Near the Ridge

• Methods only applicable to crust >3Ma

-Near-axis local isostasy invalid, topography supported dynamics and flexure*, depth won’t correlate to age and heat flow)

- Seafloor subsidence rate is anomalous due to rapid quenching
Hydrothermal Circulation
Estimating global oceanic heat flow: Approach

- Need age grid for entire sea floor
- Need bathymetry data for entire sea floor
- Determine values for $\alpha$ and $C_p$
- Calculate heat flow at every point (to desired resolution)
- Take average of all calculated heat flow values
- Multiply average heat flow ($m^{-2}$) by total surface area of ocean floor
The end

References:

Wei, Sandwell. Estimations of Heat flow for the Cenezoic Sea Floor Using Global Depth and Age Data. 2006

Cochran, Buck. Near-axis subsidence rates, hydrothermal circulation, and thermal structure of mid-ocean ridge crests. 2001