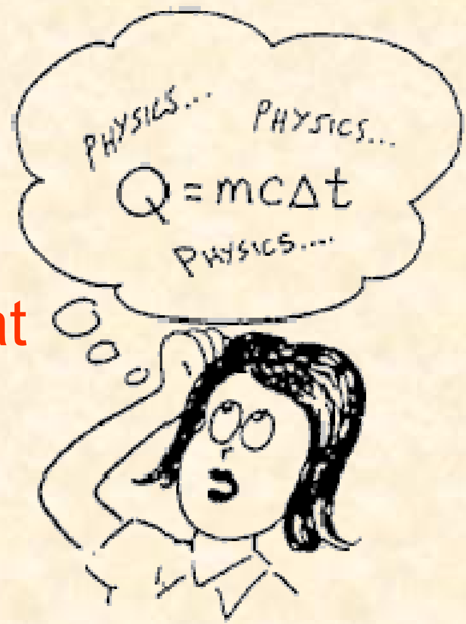
# Thermal Histories of Convective Earth Models & Constrains on Radiogenic Heat Production in The Earth

By: G. Davis, JGR, 1980

Presenting: Colleen, Caroline, Vid, Einat



# “Hot” issues

Three main issues of debate mentioned:

- Maintaining surface heat flux for long times – settled with discovery of radioactivity
- Transporting heat from depth to the surface – Conduction? Radiation? Convection?
- How much heat is now produced? Can Earth still be warming?

# General Constrains

- Earth had to be hot in early stages – considering evidence for core formation and magnetic field, rapid accretion, short-lived radioactive elements.
- Geotherm in the Archean probably steeper- hotter magmas (komatiites) and thinner lithosphere.

# Convective Heat Transfer

- Nusselt number - the ratio of total heat flux *q* through the surface, to the conductive heat $q_c$, given ΔT:

$$\mathbf{Nu = qD/K\Delta T = (R_a/R_{ac})^p}$$

- Rayleigh number:

$$\mathbf{Ra = g\alpha D^3 \Delta T/\kappa \nu}$$

- Combining them, we get:

$$\boxed{q/q_0 = (T/T0)^m}$$

m = 1+ (n+1)p, and p≈ ⅓

Large change in q – small change in T

# Thermally Activated Rheology

- Deformation by creep of dislocations or by diffusion of vacancies – **thermally activated**
- Diffusion law : $D = D_0 \exp(-H/RT)$
- Effective viscosity: $\nu \sim T\exp(H/RT)$
- $n = -\partial \ln \nu / \partial \ln T = H/RT - 1$
- Observations: mantle viscosity is ~ constant → H/RT constant → n is constant, ~20 → **m = 10** represents convection

# Model Setup

- Thermal state of the interior – represented by a characteristic temperature **T**
- Considering only post-core segregation
- Assuming a steady-state
- Solving a non-dimensional differential equation:

$$\partial T / \partial t = h - q$$

Non-dim heat flux

Non-dim heat production

- Non-dim. time: $t = t' / \tau$ , where $\tau = cT_0' / q_0$

# Results

- <u>No heat sources</u>
  - Exponential decay
  - m=1: $T=e^{-t'/\tau}$, $\tau=15$ b.y.
  - m=10: $1/T^{m-1} = 1+(m-1)t$
    - → thermal catastrophe 1.5 b.y. ago!
- <u>Constant heat sources</u>:
  - $T=q=h+(T_0-h)e^{-t}$
  - Approaches a steady state
  - Conclusions:
    - a planet with constant heat sources will become convective
    - Temperature of convective planet is buffered through thermally activated rheology

Image removed due to copyright considerations. Please see:

Davies, Geoffrey F. "Thermal histories of convective Earth models and constraints on radiogenic heat production in the Earth." *Journal of Geophysical Research* 85, no B5 (May 10, 1980): 2517-2530.

# Decaying Heat Source

- Main radioactive elements: U, Th, K.
- Define *decay constants* as $\lambda = \ln 2 \, \tau / \tau_R$
- Two radioactive abundance models: $\lambda = 6$ , $9$
- Example results:

Image removed due to copyright considerations.
Please see:

Davies, Geoffrey F. "Thermal histories of convective Earth models and constraints on radiogenic heat production in the Earth." *Journal of Geophysical Research* 85, no B5 (May 10, 1980): 2517-2530.

T, h, q as function of time

Image removed due to copyright considerations.
Please see:

Davies, Geoffrey F. "Thermal histories of convective Earth models and constraints on radiogenic heat production in the Earth." *Journal of Geophysical Research* 85, no B5 (May 10, 1980): 2517-2530.

q in time, for different $h_0$ values
transition from “hot” to “cold” past

# Constrains On Radioactive Heat Production

- Assuming a hot history: q' cannot be $\geq 5$ times today's later than 2.5 b.y. ago

  → $h_0 \geq 0.2$

- Assuming a cold history: q' cannot be smaller than today's ($q \geq 1$) 1 b.y ago

  → $h_0 \leq 0.7$

- A plausible warm history: taking hot temperature for Archean upper mantle → $2 \leq q \leq 5$ 3 b.y. ago → $0.45 \leq h_0 \leq 0.55$ ($\lambda = 9$)

# Radioactive Heat Source Concentrations

- Chondritic Coincidence: the heat loss per unit mass of the earth $\approx$ the radiogenic production per unit mass of chondritic meteorites
- Using above values for heat production rate, and observed values for heat loss, conclude: **present heat production rate is very similar to that of carbonateous of K-depleted chondrites**
- Other types of chondrites: rate is too high.

# Conclusions

- Imbalance between heat production and heat loss – about half of the heat was generated over the past few billion years
- Heat production to heat loss ratio $\approx$ 0.5
- Rate of radiogenic heat production similar to carbonateous chondrites
- Results dominated by strong temperature dependence of rheology.