Physics + Chemistry of the Earth.

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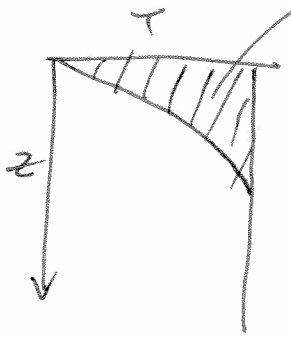
KITP

Age of the Earth? /

* 4.55 Gy.
* ~~heat~~ history.

Lord Kelvin

Assume conduction



$$q = k\frac{dT}{dz}$$

$$q = k\frac{\Delta T}{\sqrt{\pi \kappa t}}$$

↳ t

Kelvin got 20 My.

of course Kelvin was wrong.

geologists salt sedimentary layers.

Why?

Heat production, radioactivity - Rutherford

K, U, Th decay → generate heat

formed during ~~the~~ supernova that predated the collapse of the solar nebula.

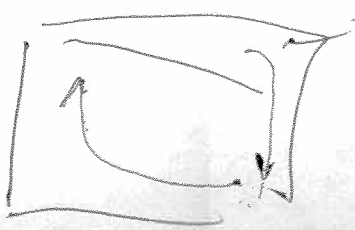
$$q_m = k\frac{\Delta T}{\sqrt{\pi \kappa t}} + \dot{H}$$

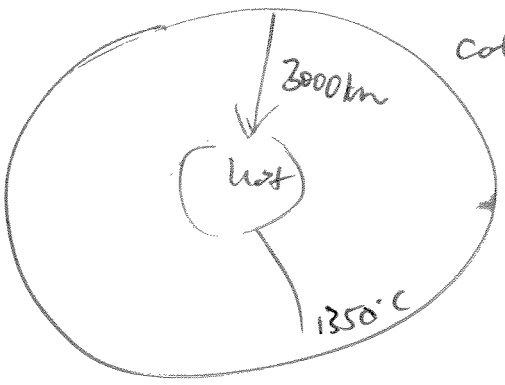
20 My → @ 200 My

Not why Kelvin was wrong.

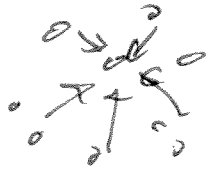
Kelvin was wrong because he ignored convection

How do we know the Earth is convecting?





The Earth is hot because of primordial accretionary heat and radiogenic heat production.



Is the Earth losing heat by conduction? or convection

$$Ra \sim \frac{\rho_0 \alpha g \Delta T L^3}{\kappa \eta}$$ — SOLID STATE Convection

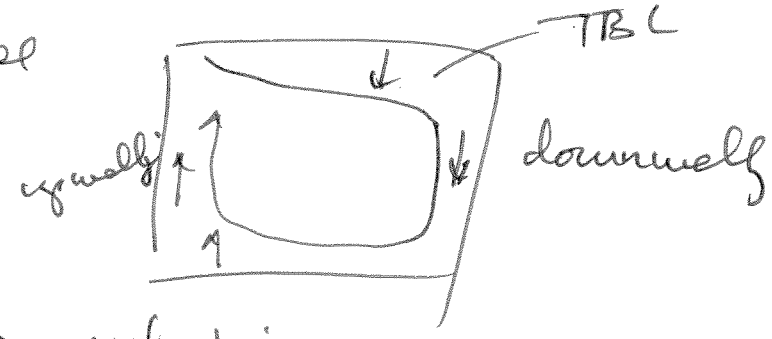
$\eta = 10^{21}$ Pa.s compare with water 10^{-3} Pa.s.

but $\sim L^3$ is large and so is ΔT

$Ra \sim 10^7 > Ra_{cr} \sim 10^3$ Earth convects.

sidebar. convection and Re

$$Ra \sim \left(\frac{q_{conv}}{q_{cond}}\right)^{\beta}$$



↳ velocities

$$Re = \frac{\rho U L}{\eta} \sim 0$$ no turbulence, steady laminar flow, reversible flow (Taylor)

$$\text{Prandtl \#} = \frac{\eta}{\rho \kappa} = 10^{26}$$ infinite.

- momentum diffusivity high
- p transferred instantly
- normal b.l. are not.

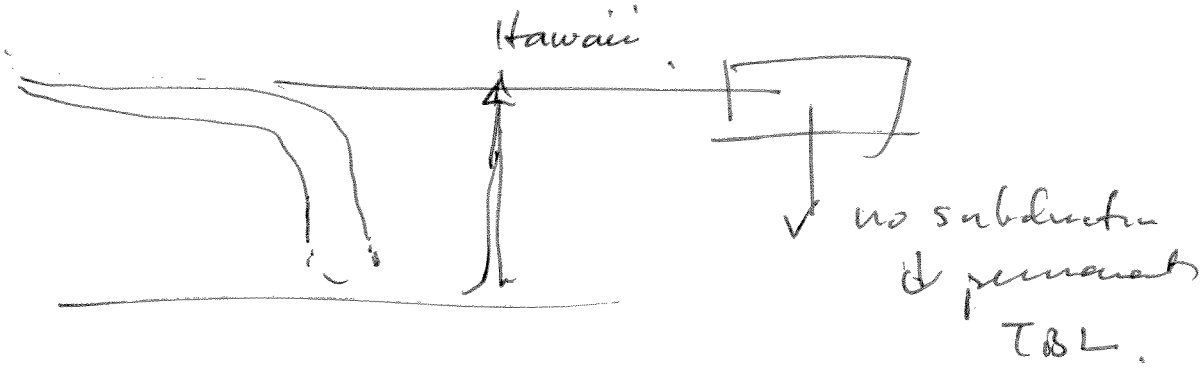
>

Conv. on Earth is easy — go back to conv

BUT . . .

$$\eta = \eta_0 e^{E/RT}$$

α change



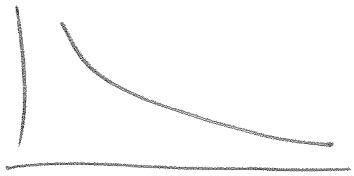
other complications

are composition. ⇝ η

comp stratification

How do we know the Earth convects. Proof?

① heat flow

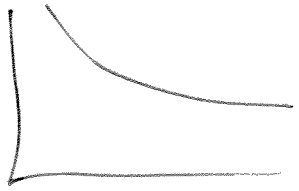


but more important

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

t age of crust

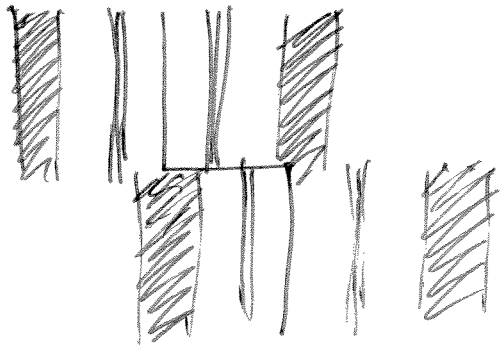
→ heat flow



← important

x/v

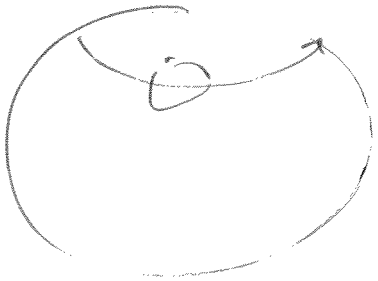
② magnetic polarity reversals



→ recorded in the rocks as they form.

tape recorder. melt.

③ Seismology



– can even view downwelling

crust forms

So what is the age of the Earth

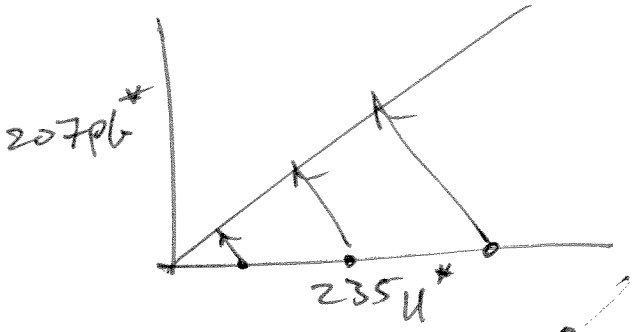
$^{238}U \rightarrow {}^{206}Pb + x\,{}^{4}He + 8e^-$ + heat

$t_{1/2} \sim$ ~~10 Gy~~ 4.5 Gy

238 / 206 / 32

$^{235}U \rightarrow {}^{207}Pb + 7\,{}^{4}He \sim 1$ Gy

235 / 207 / 28



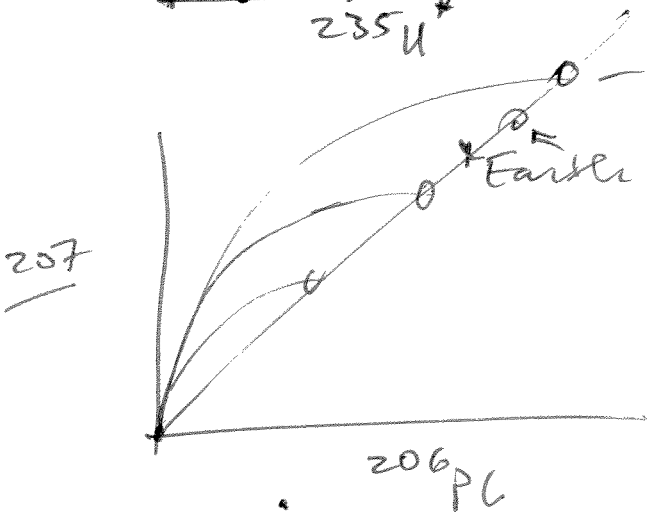
$\frac{dN}{dt} = -\lambda N$

$N = N_0 e^{-\lambda t}$

$N_0 = N + D$

$N = N_0 - D$

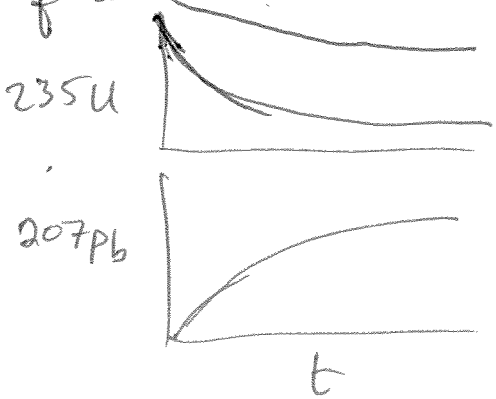
$N_0 - D = N_0 e^{-\lambda t}$

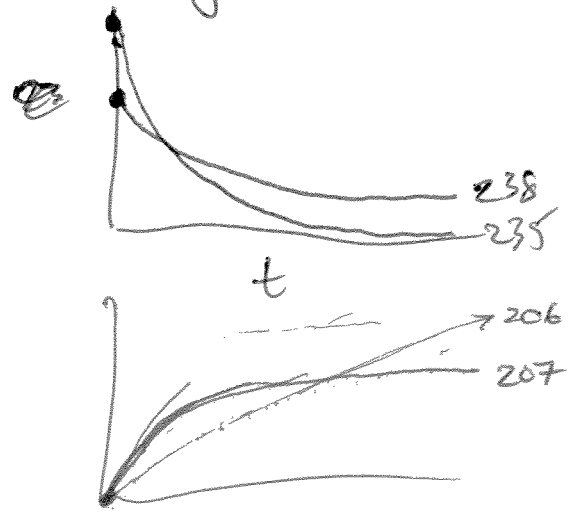


$D = N_0(1 - e^{-\lambda t})$

$D = N(e^{\lambda t} - 1)$

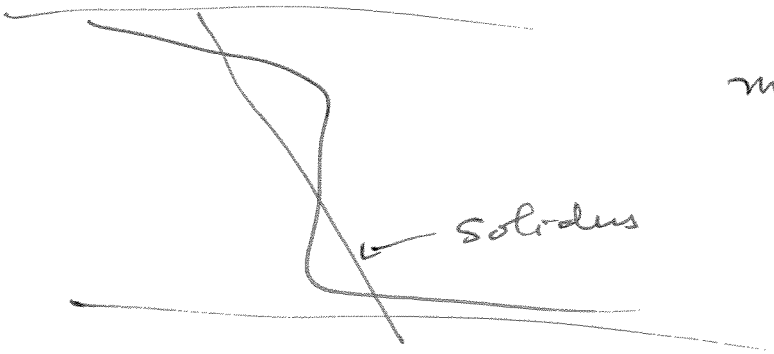
in fact we can't date Earth directly.





Consequences of convection ?

different of Earth



melting generated by decompression

$$\frac{dP}{dT} = \frac{\Delta S_{rxn}}{\Delta V_{rxn}}$$

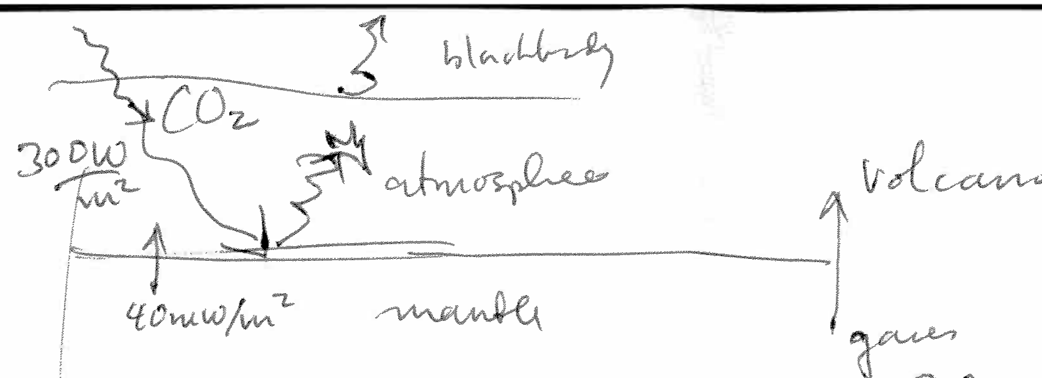
$\rho_m < \rho_s$

$$V = \frac{\Delta \rho g L^2}{\eta}$$ ← permeability

The other thing is the role of volatiles

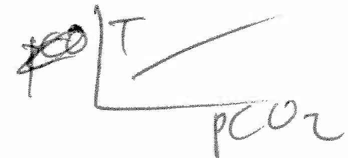
$S = -\sum R x \ln x \rightarrow \infty$

↳ depresses solidus



CO_2, H_2O, SO_2

- greenhouse gas
- gets hot



Negative feedbacks $H_2CO_3 = H_2O + CO_2$

1) $CO_2 + CaSiO_3 = CaCO_3 + SiO_2$

chemical weathering

H_2O

- on Earth this works ~ 100,000 timescales
- modulates . .

2) $CO_2 + H_2O + h\nu = CH_2O + O_2$

photosynthesis ⟶

⟵ respiration

burial of org. matter

net burial of CH_2O . . . ↑ O_2 gas ..

OIL = organic carbon burial! enhanced preservation

* Cretaceous oil abundant - why?

Warm climate ~ 25°C at poles
high sea level
Low pO_2 in oceans due to warm T.
dynamic topography
inland shallow seas

} ⟶ period.

beginning of closure of Tethys ocean

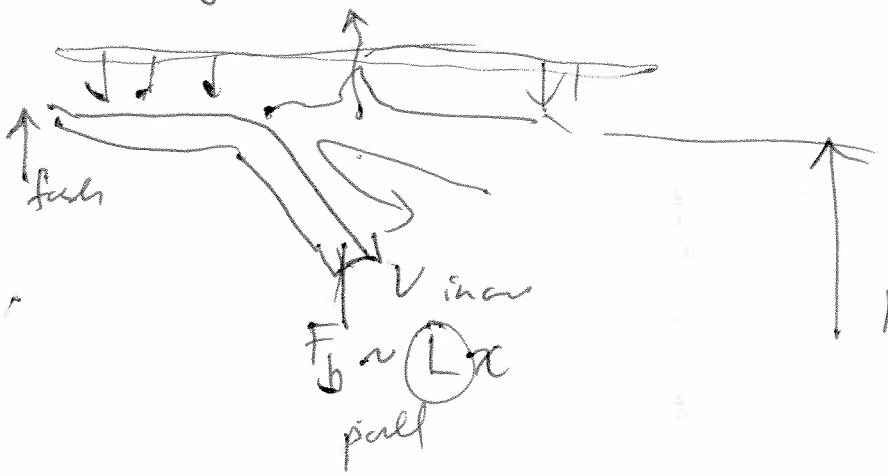
mass extinction C-T B

magnetic quiet period
arcs + LIPS.

h: T → h. pCO_2

- due to more volcanoes
- why more volcanoes?

$$= -\frac{\bar{M}}{\frac{dP}{dt}} + C$$



Prandtl = inf.

N. Fe limited

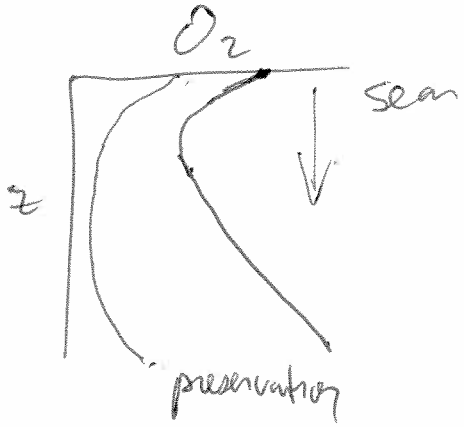
ash fall

ash - bentonite - blade shale

phytoplankton bloom

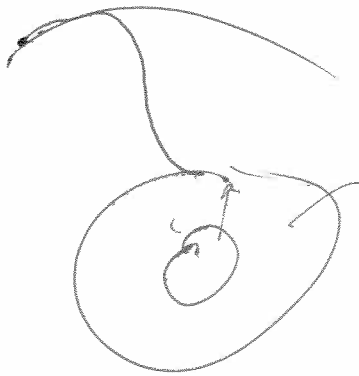
Source

reservoir rock



oil

→ finally we have



convection.

but if you have slabs that are stuck or core, it will stabilize it, keep from overturning