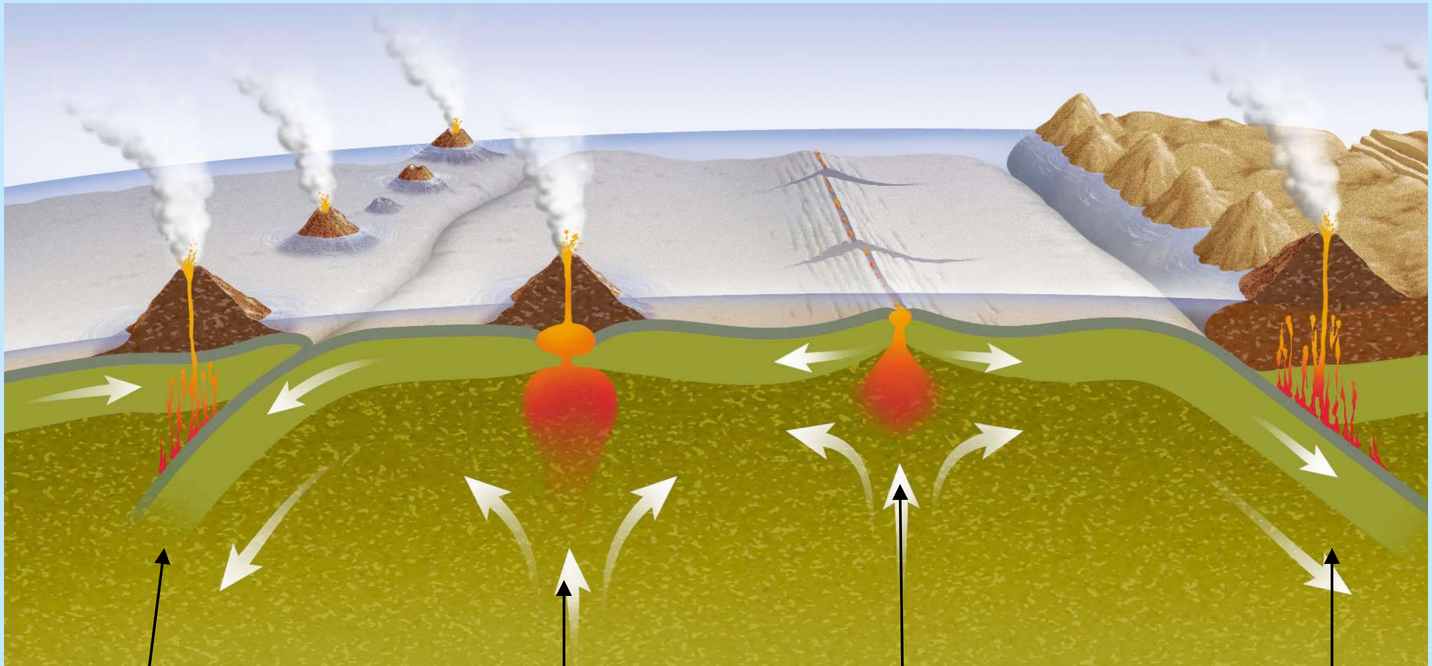
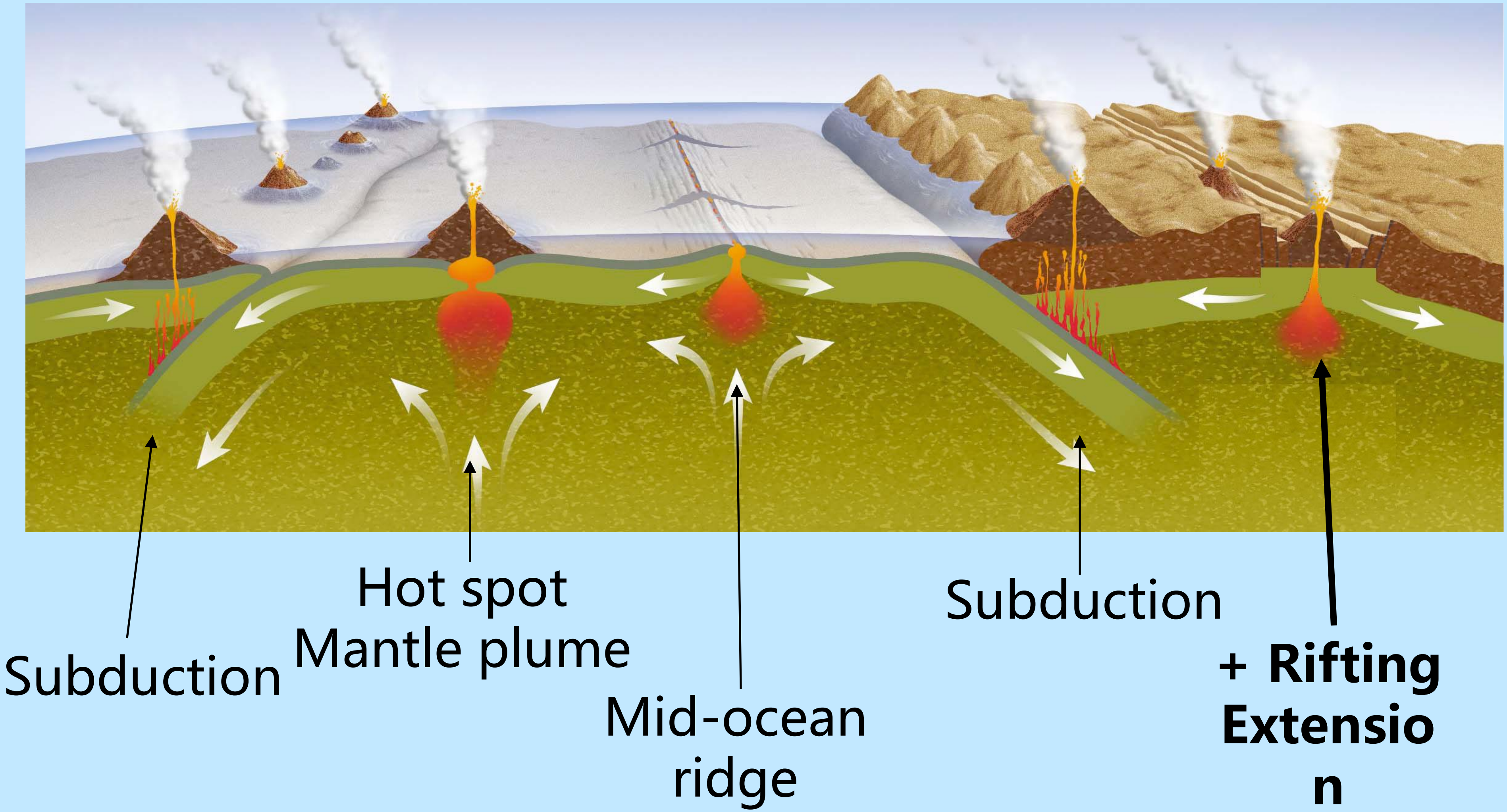
CONTROLS ON THE GLOBAL RATE OF ERUPTION ON EARTH

Claude Jaupart
Institut de Physique du Globe de Paris


Hot spot
Mantle plume
Subduction
Mid-ocean
ridge
Subduction



+ upwellings (small-scale convection) at the base of thick continental lithosphere

Mid-ocean ridge volcanism

Φ = degassing rate (in moles/yr or kg/yr)

$$\Phi = C_A \; h \; C_{CO2}$$

C_A spreading rate (in area per unit time)
h = depth of melting
C_{CO2} = concentration

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Relationship between oceanic heat loss and degassing r

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Relationship between oceanic heat loss and degassing r

$$Q_{oc} = \int_0^{\tau_m} q(0,\tau)\frac{dA}{d\tau}d\tau$$

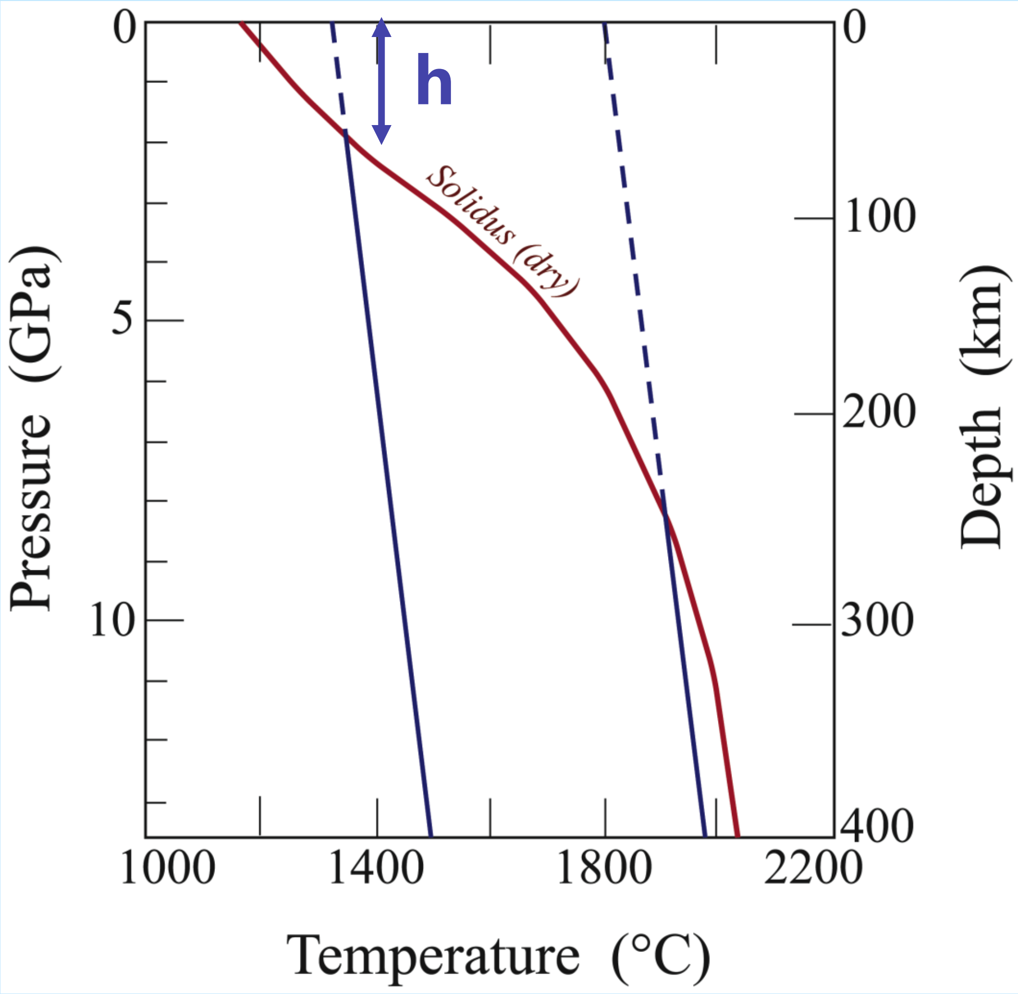
with

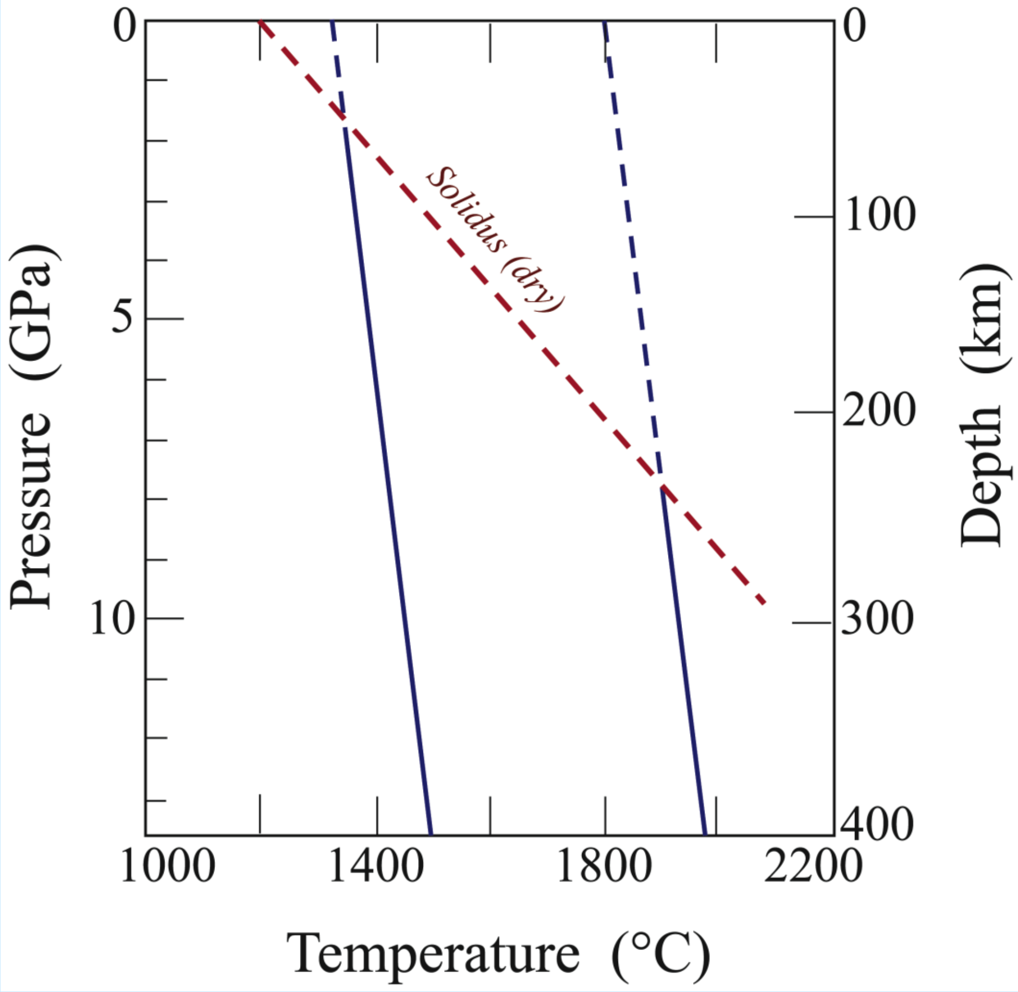
$$q(0,\tau) = \frac{T_M}{\sqrt{\pi\kappa\tau}}$$

Area vs. age

$$\frac{dA}{d\tau} = C_A f\left(\frac{\tau}{\tau_m}\right)$$

τ = age
τ_m = maximum age of sea floor
f = dimensionless age distribution


h
Solidus (dry)
Pressure (GPa)
Depth (km)
Temperature (°C)
0
5
10
0
100
200
300
400
1000
1400
1800
2200



0
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Relationship between oceanic heat loss and degassing r

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$$T_{solidus} \approx T_{so} + \gamma_1 z$$
$$T_{isentrope} = T_M + \gamma_2 z$$

$$h = (T_M - T_{so})/(\gamma_1 - \gamma_2)$$

$$\Phi \propto Q_{oc} \, C_{CO2} \frac{1}{\sqrt{\kappa \, \tau_m} \int_0^1 \frac{f(u)}{\sqrt{u}} du} \; \frac{T_M - T_{so}}{T_M}$$

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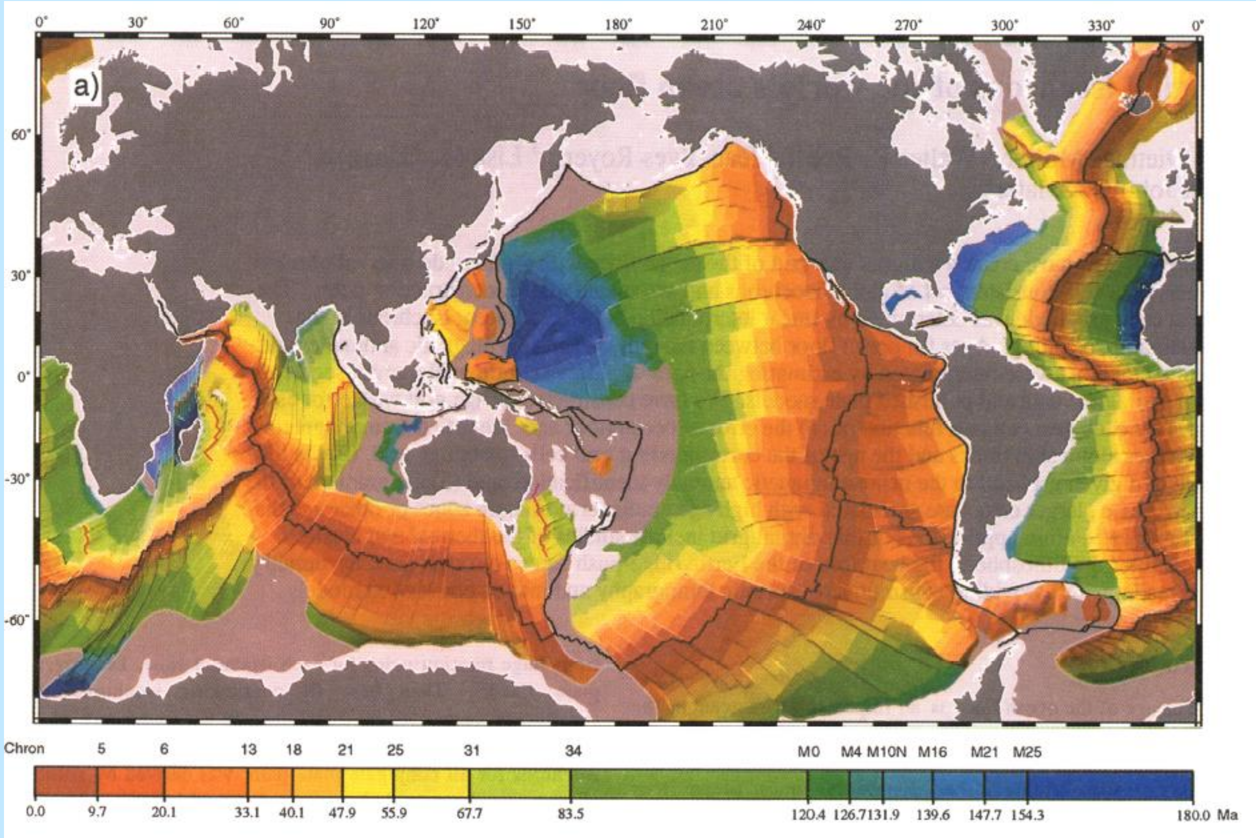
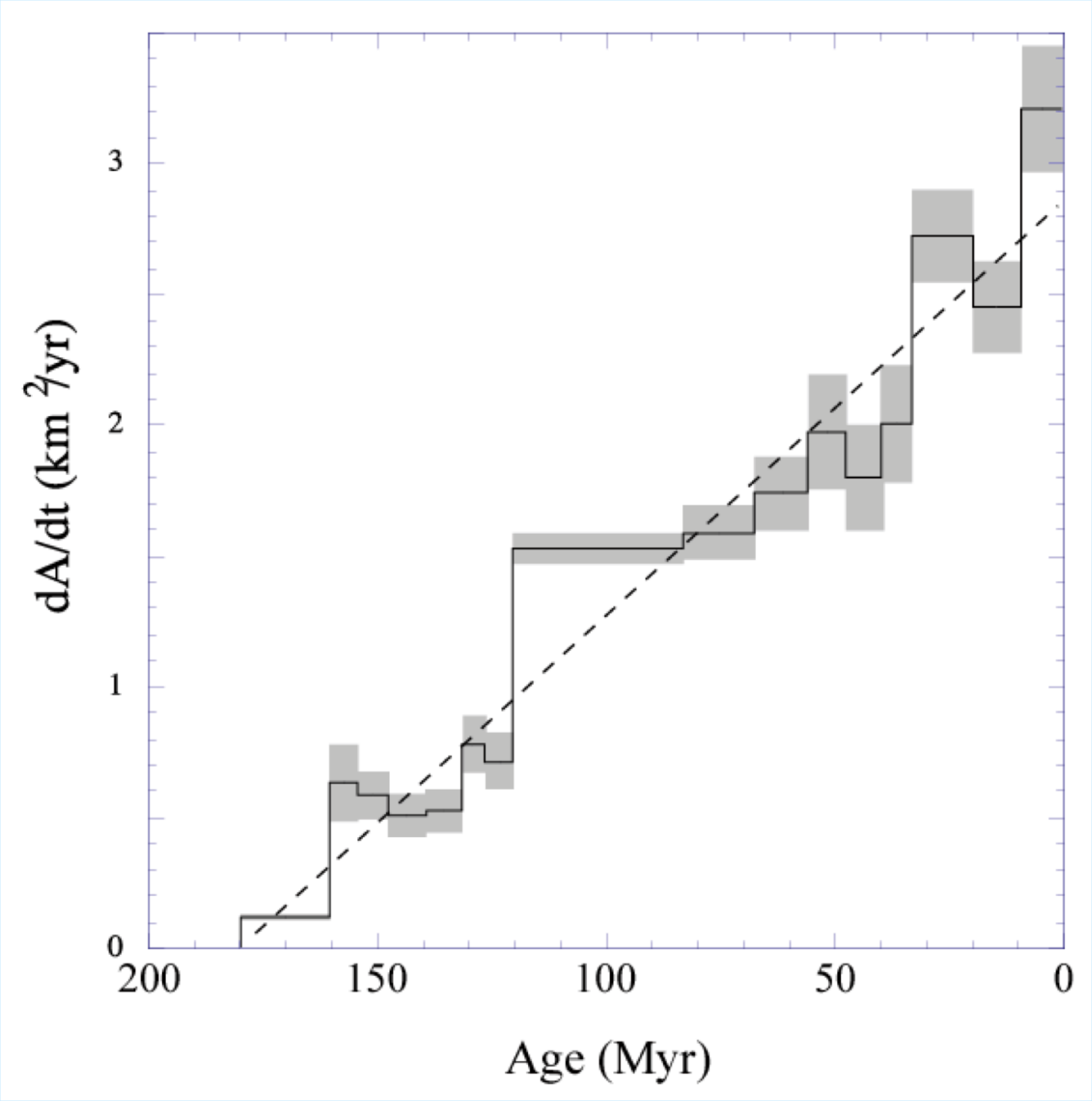


OCEANIC HEAT LOSS = 29 ± 1 TW
(with no contribution from "hot spots")

Main uncertainty :
time-variations of the distribution of sea floor ages

Area (of sea floor) versus age : a peculiar distributi



Probably not representative of long-term average

SECULAR COOLING EQUATION

$$M\,C_p \frac{dT}{dt} = -\int q_r\, dA + \int H\, dV$$

= - heat loss

+ internal heat production

Note : negligible contribution of contraction,

zero contribution of dissipation

BSE heat production (from U, Th, K contents)

Reference	H ($pW\ kg^{-1}$)	$\int H\, dV$ (TW)
Hart & Zindler (1986)	4.9	19
McDonough & Sun (1995)	4.8 ± 0.8	19 ± 3
Palme & O'Neill (2003)	5.1 ± 0.8	20 ± 3
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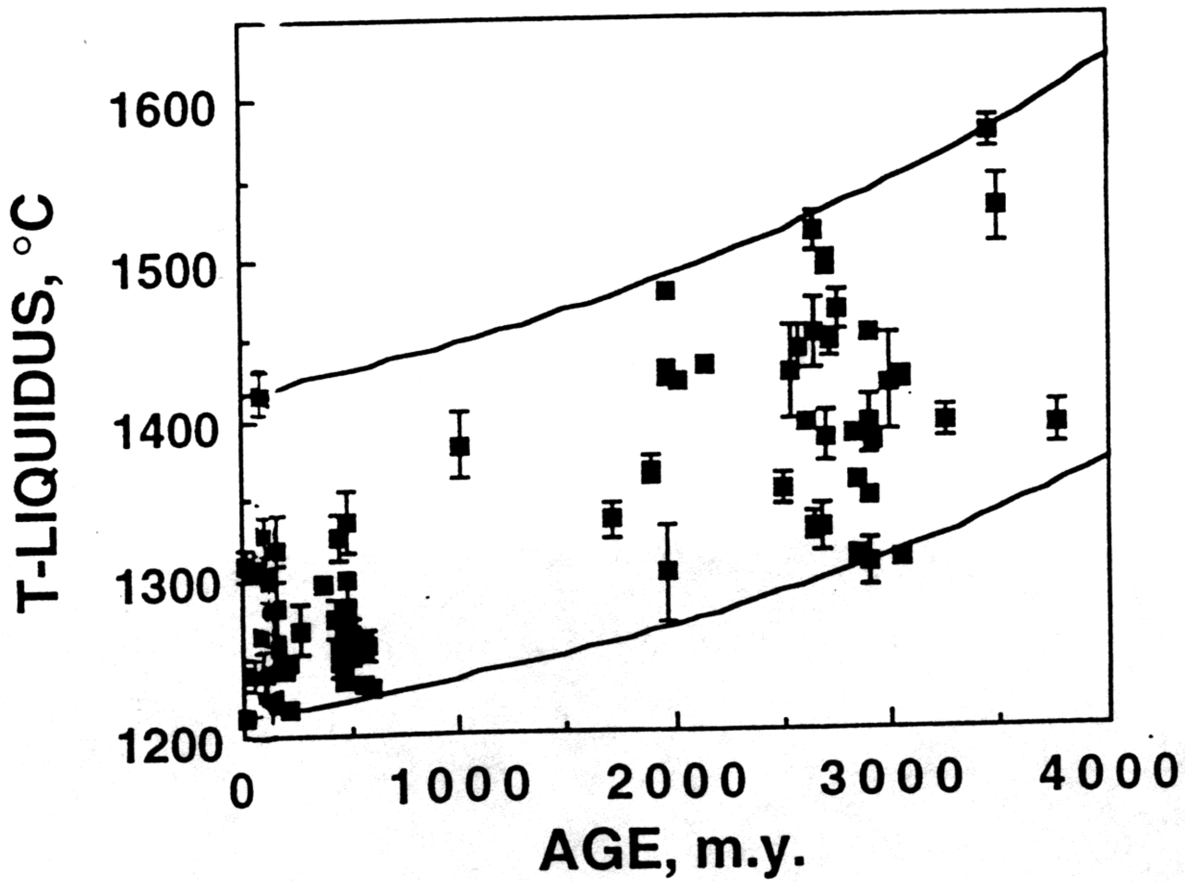
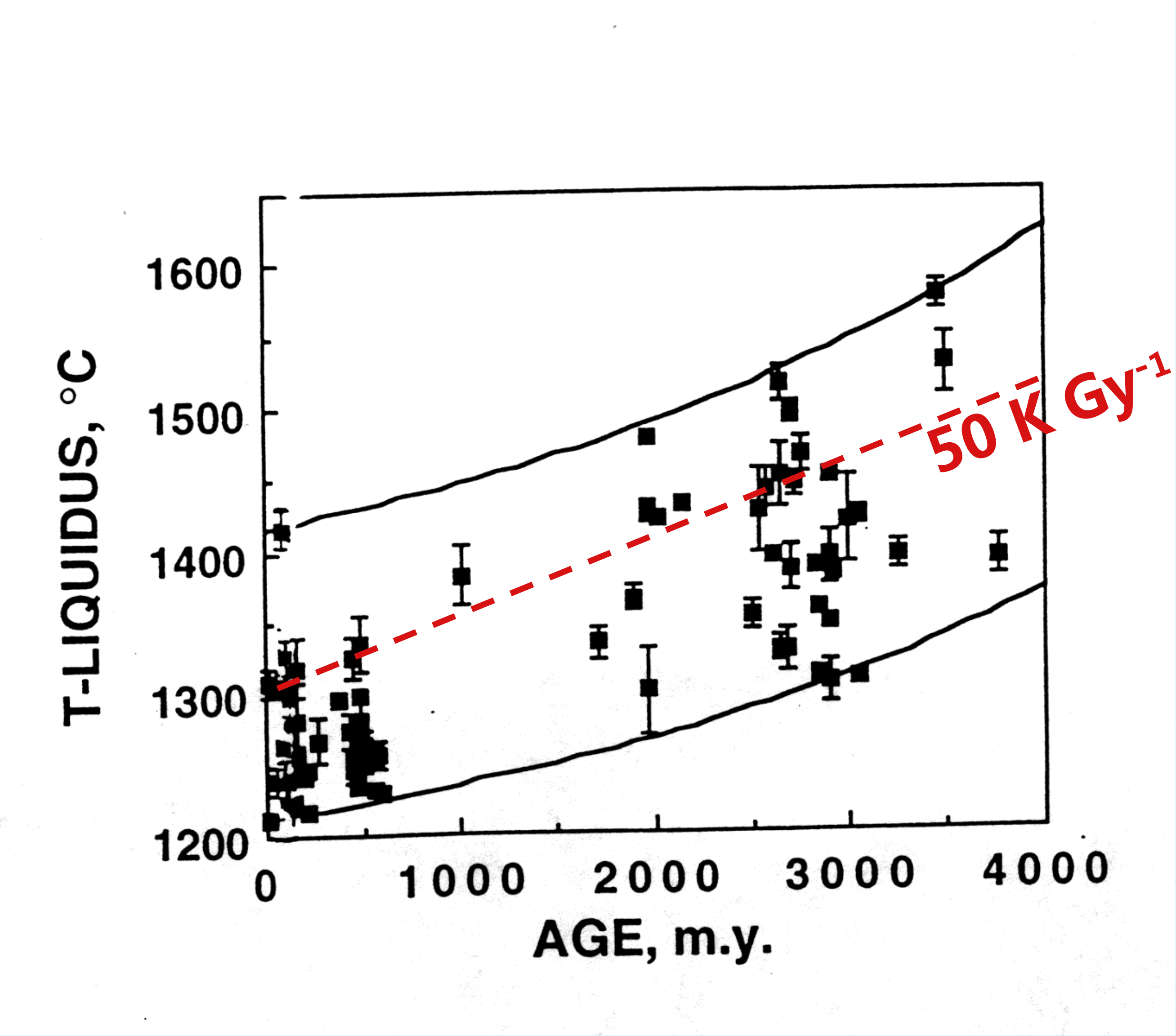
Earth's secular cooling rate

From the composition of mid-ocean ridge basalts and similar magmas



From Abbott et al. (1994)



$\approx 50 \pm 25$ K Gy^{-1}

$$M\,C_p\,\frac{dT}{dt} = -\int q_r\,dA + \int H\,dV$$

Secular cooling rate $\approx$ 25 - 75 K Gy^{-1}

(average) $\approx$ 6 - 18 TW

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Bulk Silicate Earth (BSE) radiogenic heat production

= 13 - 23 TW (a)

Present-day heat loss = 43 - 49 TW (b)

Present-day cooling rate (a-b)

= 20 - 36 TW

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(1) Rates of melting and of degassing
at mid-ocean ridges are related to the oceanic heat los
(and hence to the Earth's energy budget)

(2) Rate of subduction is also related to
the oceanic heat loss

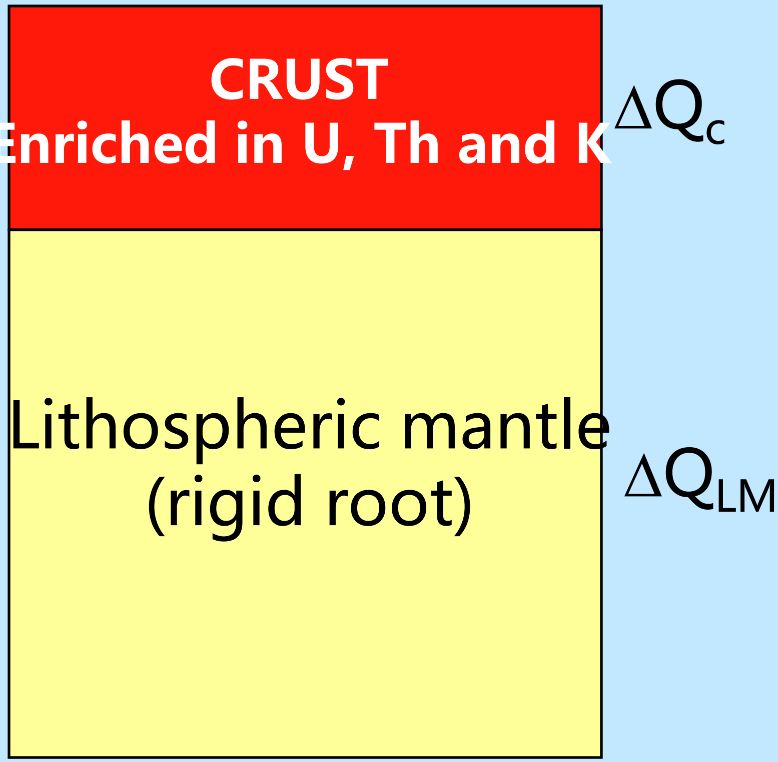
(3) These rates vary on (at least) two different time-scal

- a. Secular cooling
  (and rundown of radioactivity)
- b. Wilson cycle of assembly and dispersal
  of continents (≈ 400-500 Myrs)

Continents

Heat loss through continental lithosphere

$$Q_s = \Delta Q_c + \Delta Q_{LM} + Q_b$$



Basal heat flux Q_b

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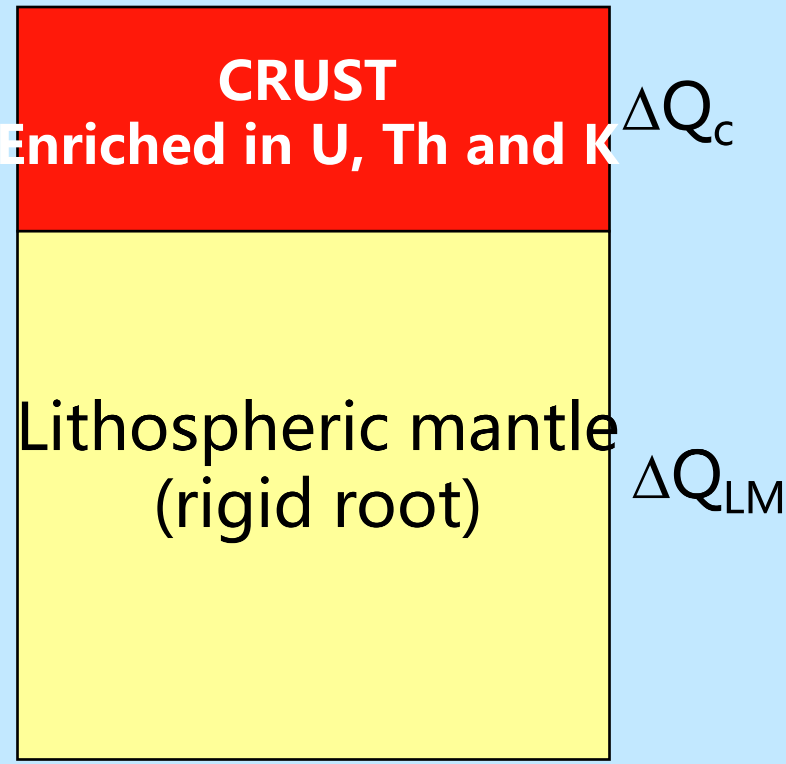
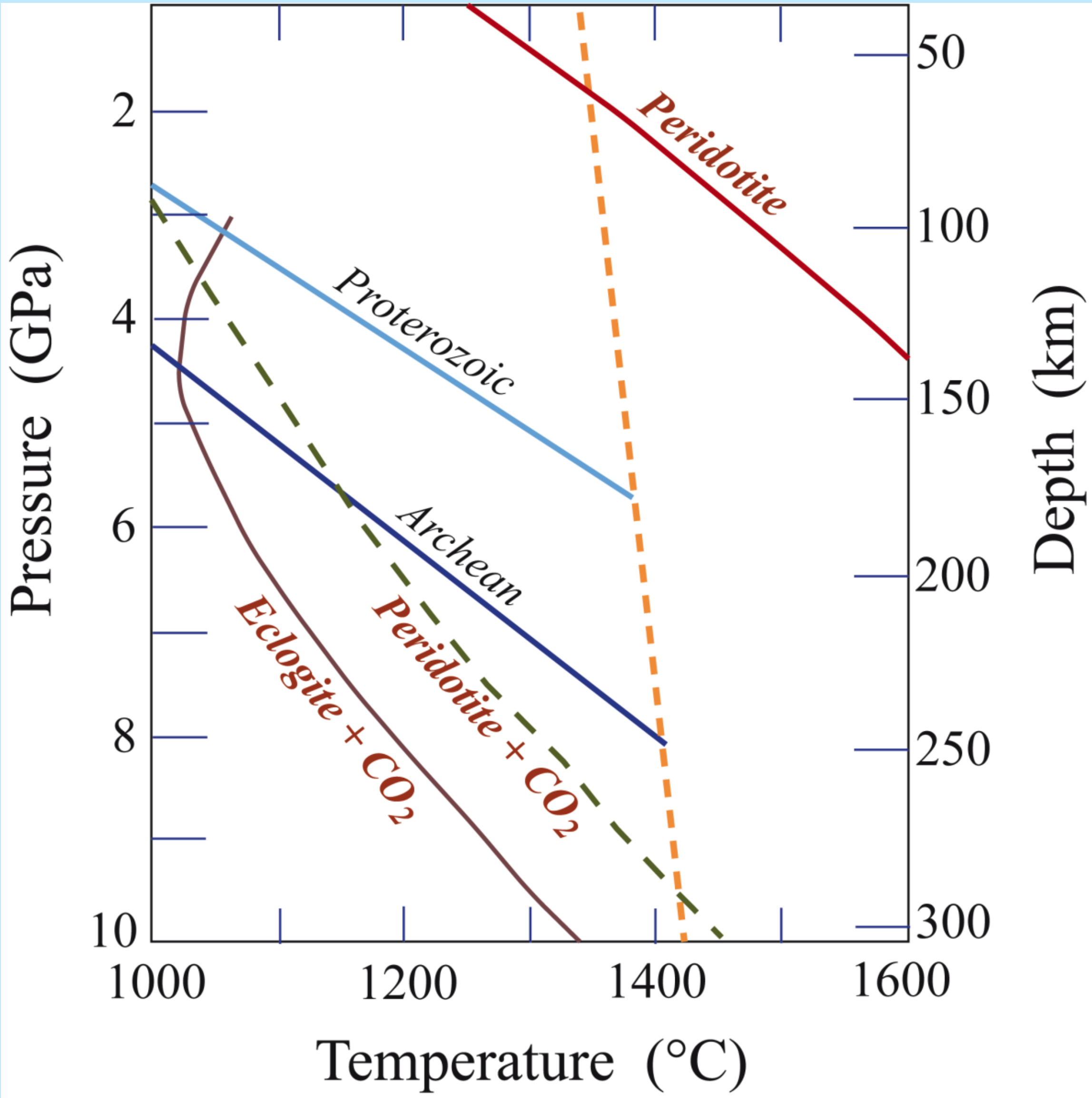
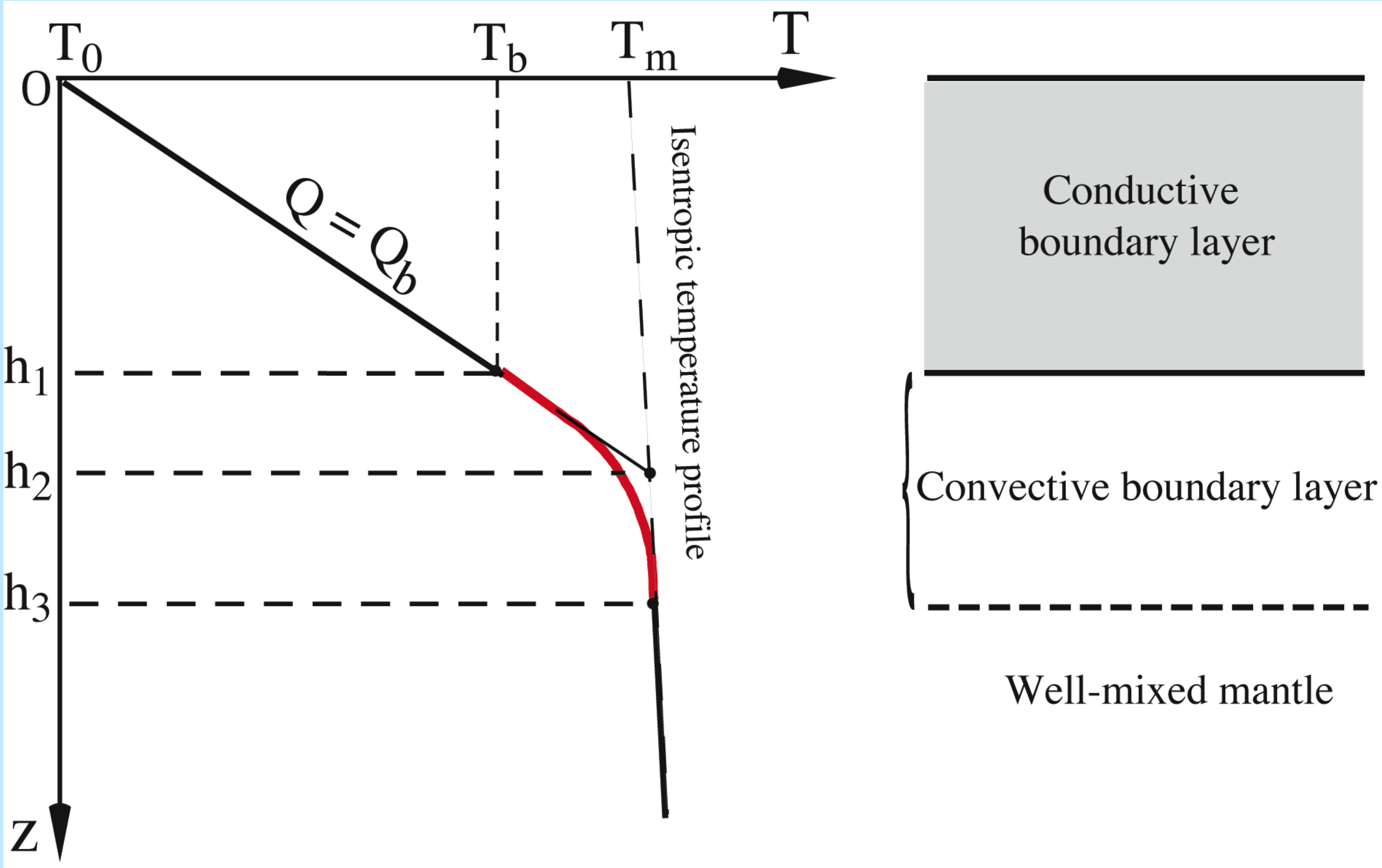


Basal heat flux Q_b

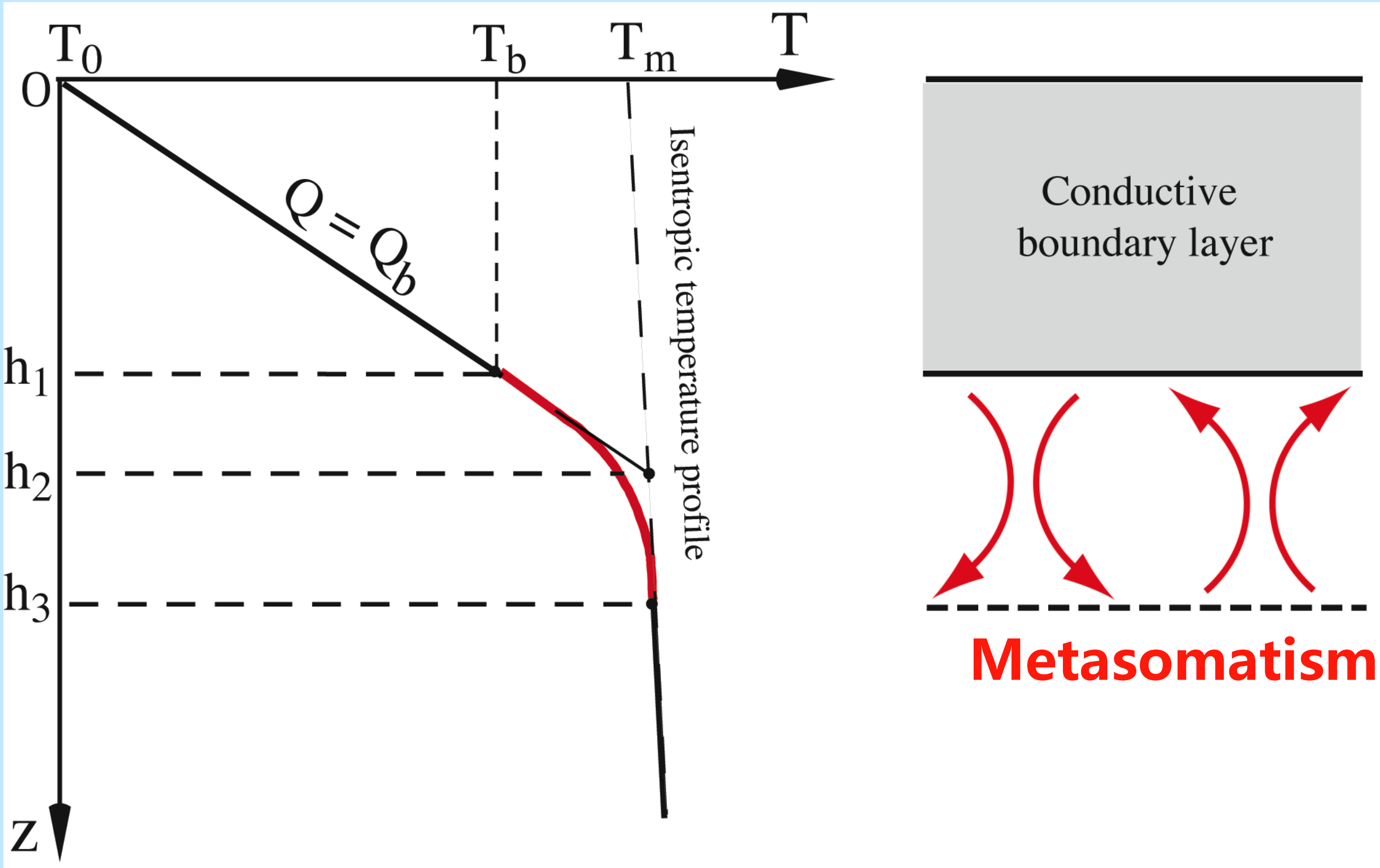
≈ 15 mW m^{-2}



Peridotite
Proterozoic
Archean
Eclogite + CO_2
Peridotite + CO_2
2
4
6
8
10
50
100
150
200
250
300
1000
1200
1400
1600
Pressure (GPa)
Depth (km)
Temperature (°C)



T
T_0
T_b
T_m
O
$Q = Q_b$
Isentropic temperature profile
h_1
h_2
h_3
z
Conductive boundary layer
Convective boundary layer
Well-mixed mantle



Metasomatism ?

CO_2 release due to small-scale convection at base of thick continental lithosphere

Renewal of boundary layer of thickness δ over time τ

$$\Phi_{cont} \propto A_{cont} \; C_{CO2} \, \delta / \tau$$

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ΔT set by rheology : depends weakly on temperature and pressure ($\approx 150\,^\circ C$)

$$\Phi_{cont} \propto C_{CO2} \, Q_{cont}$$

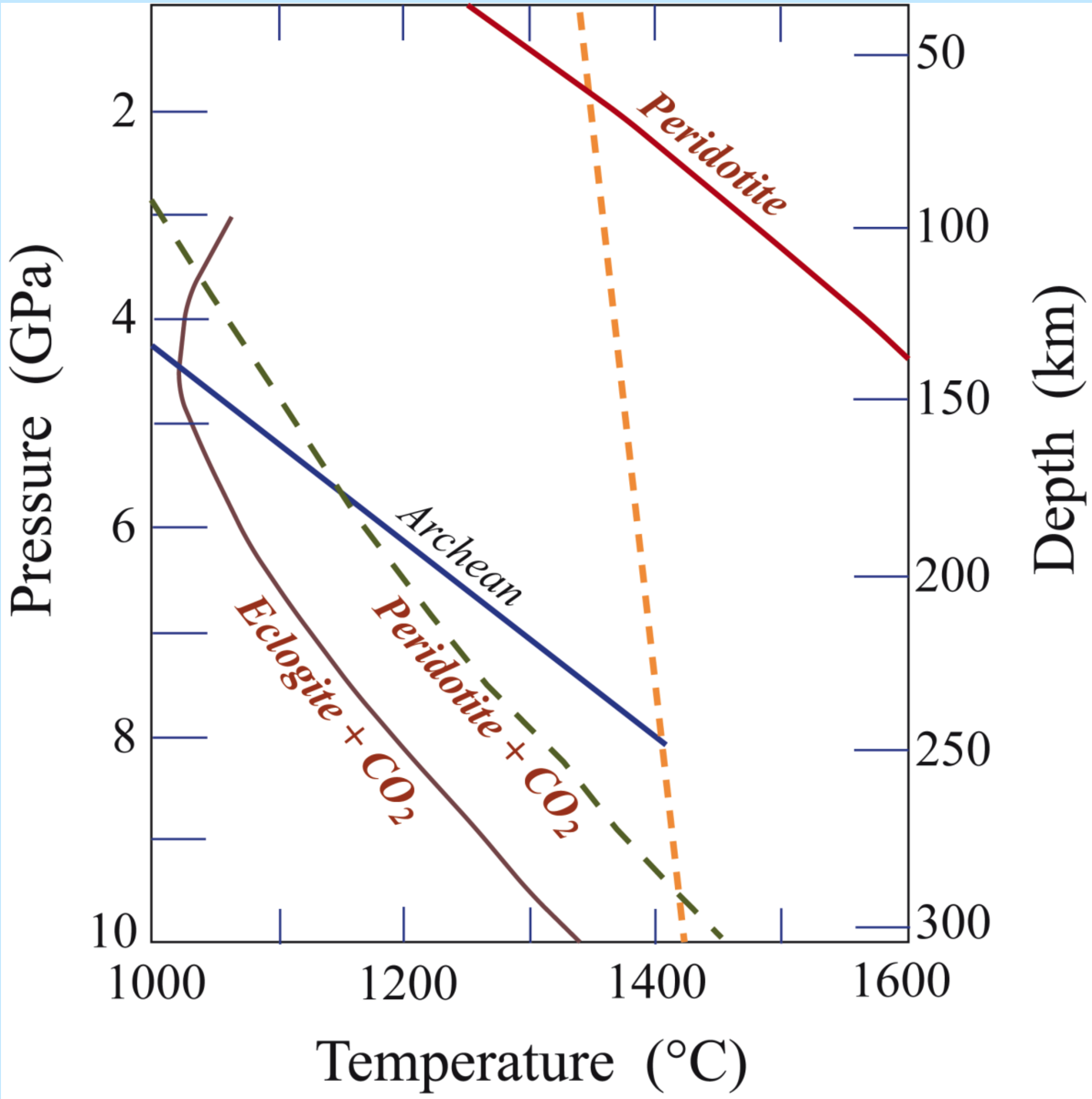
Global rate of mantle processing through small-scale convection

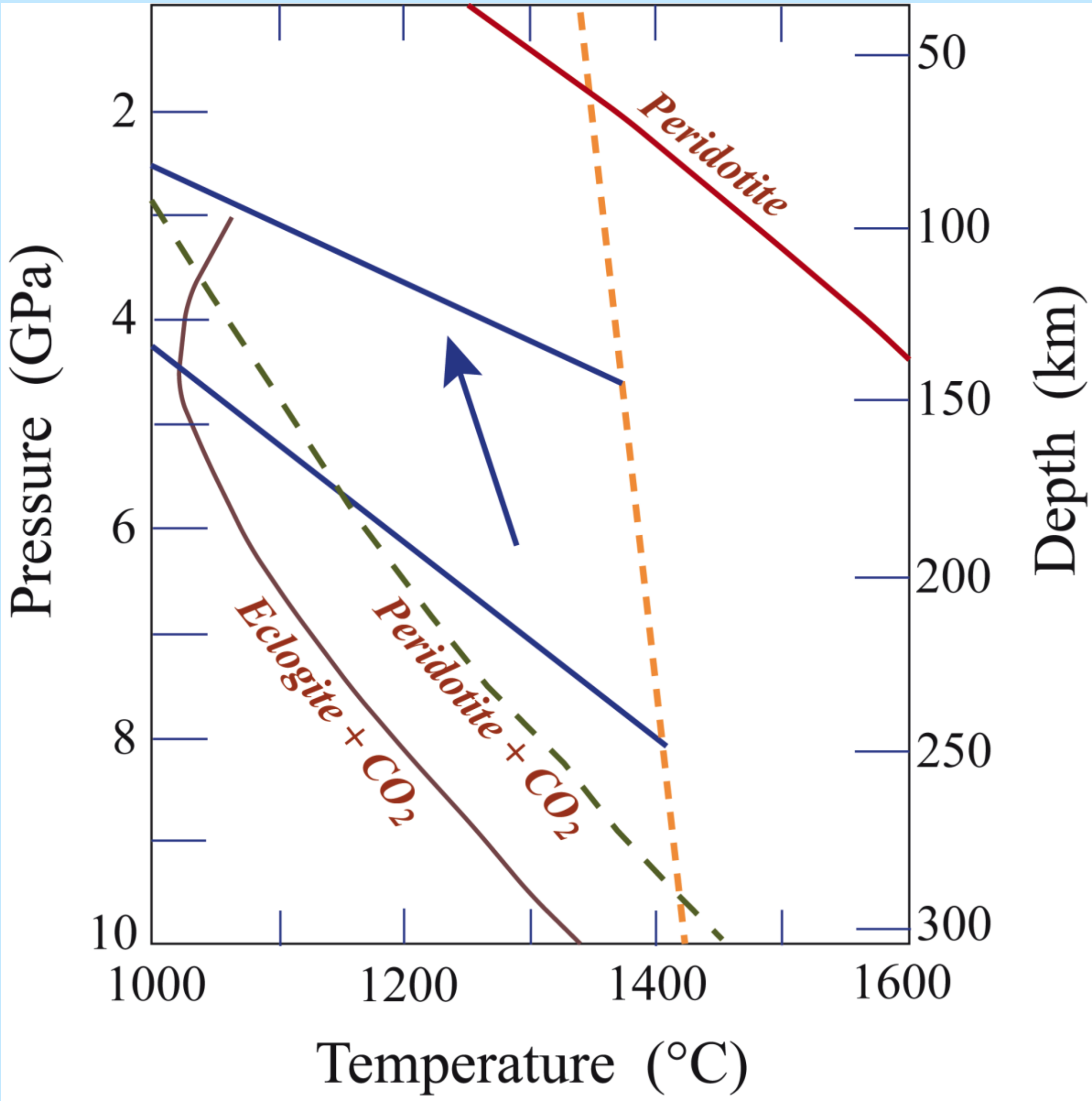
For $Q_{cont} \approx 15$ mWm^{-2}

Volume rate $\Phi_v \approx 300$ km^3/yr

(at mid-ocean ridges ≈ 160 km^3/yr)

Rifting and/or extension

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Peridotite + CO_2
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Zones of extension and rifting

* Diffuse volcanism (small cones)
* ≈ 15% of Earth's surface (oceans and continents)
* Physical mechanism poorly understood
* Poorly documented

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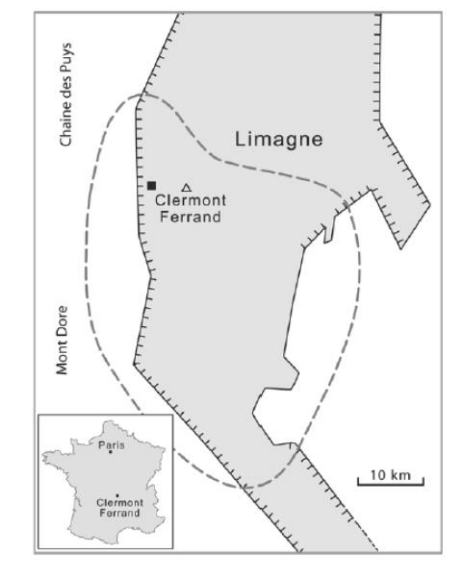

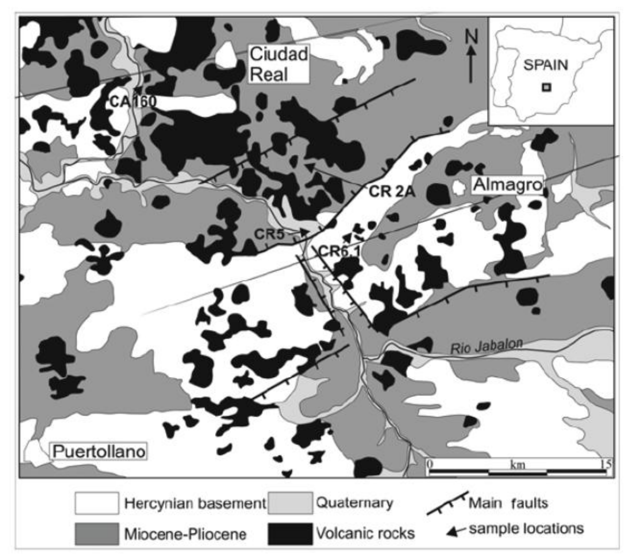

France: Limagne graben (23-0 Ma)   *Spain: Calatrava (≈ 4-1.5 Ma)*

Two areas where carbonate volcanism
had **not** been identified ten years ago

CONCLUSIONS

Controls on eruption rate =

(1) cooling of the Earth
(depends on BSE composition
and characteristics of sea floor spreading)

(2) convection at the base of continents

(3) extension/rifting events

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Average MORB source (Su, 2000; Langmuir et al., 2005)	2.8	**11**	**18**
Crustal + lith. mantle heat production (Jaupart & Mareschal, 2003; Rudnick & Gao, 2003)	/	**7 ± 1**	