THE LONG-TERM EVOLUTION OF THE GEOBIOSPHERE

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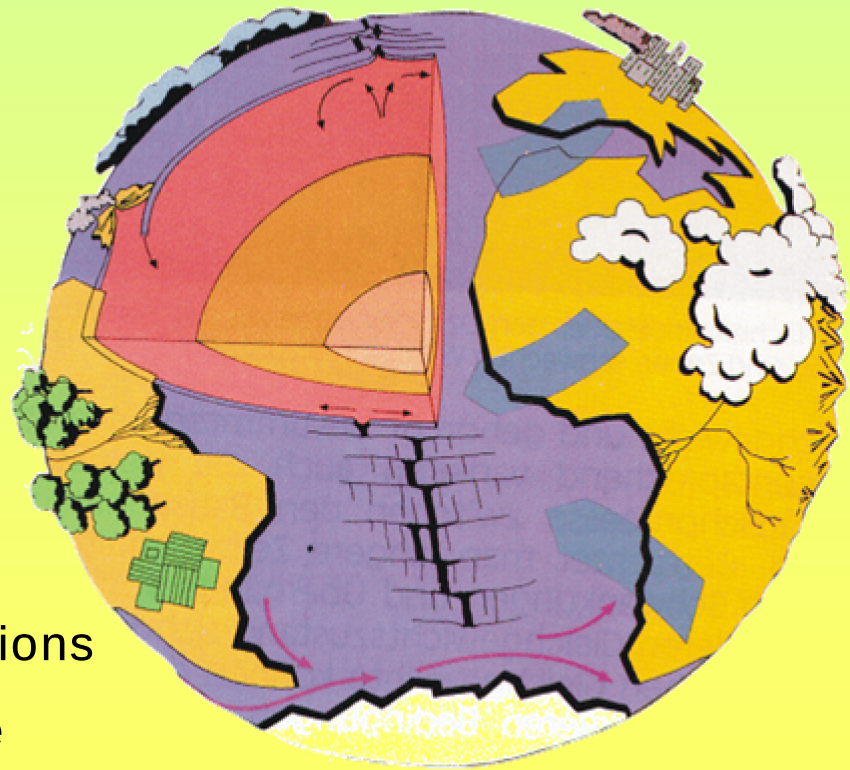
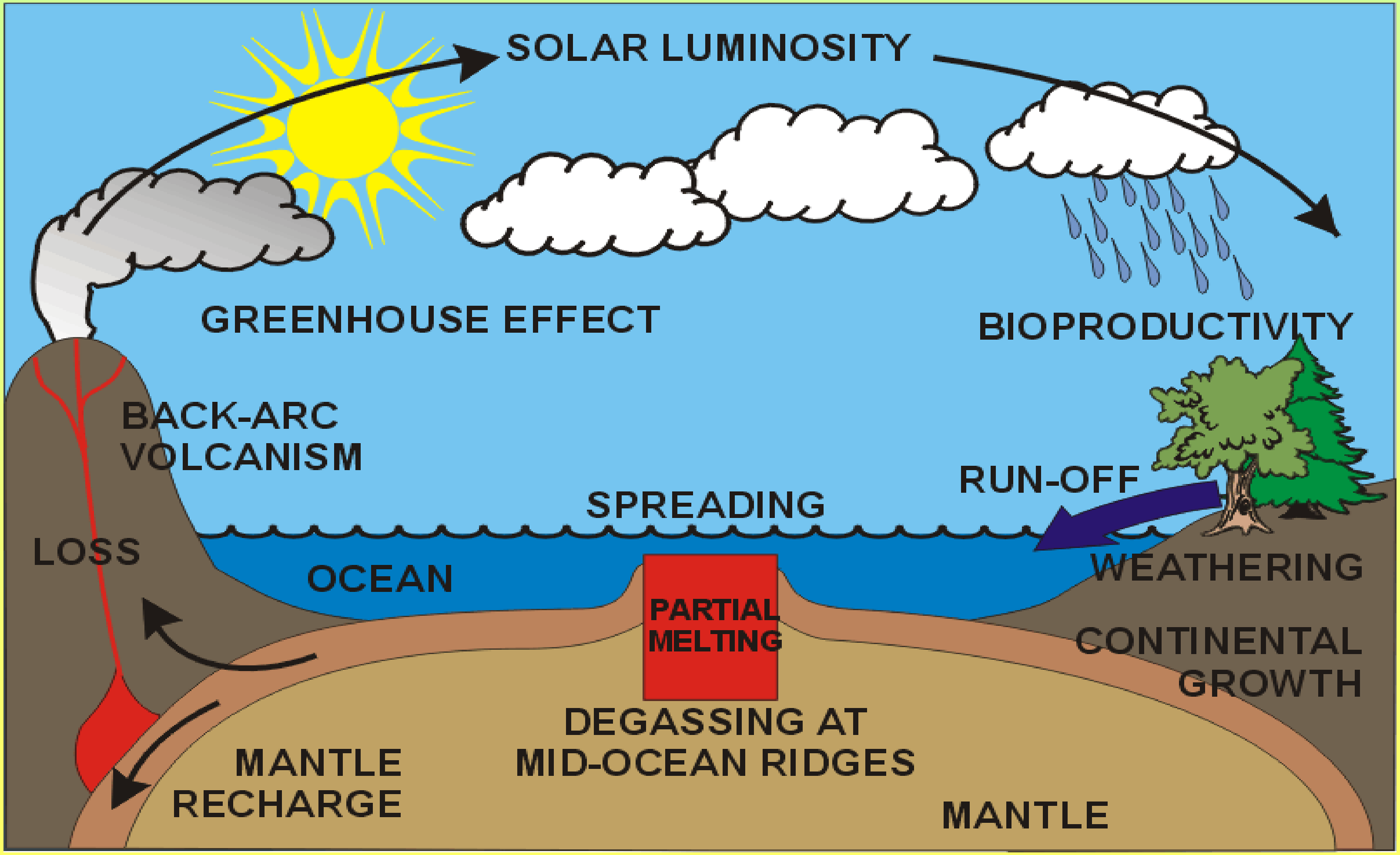
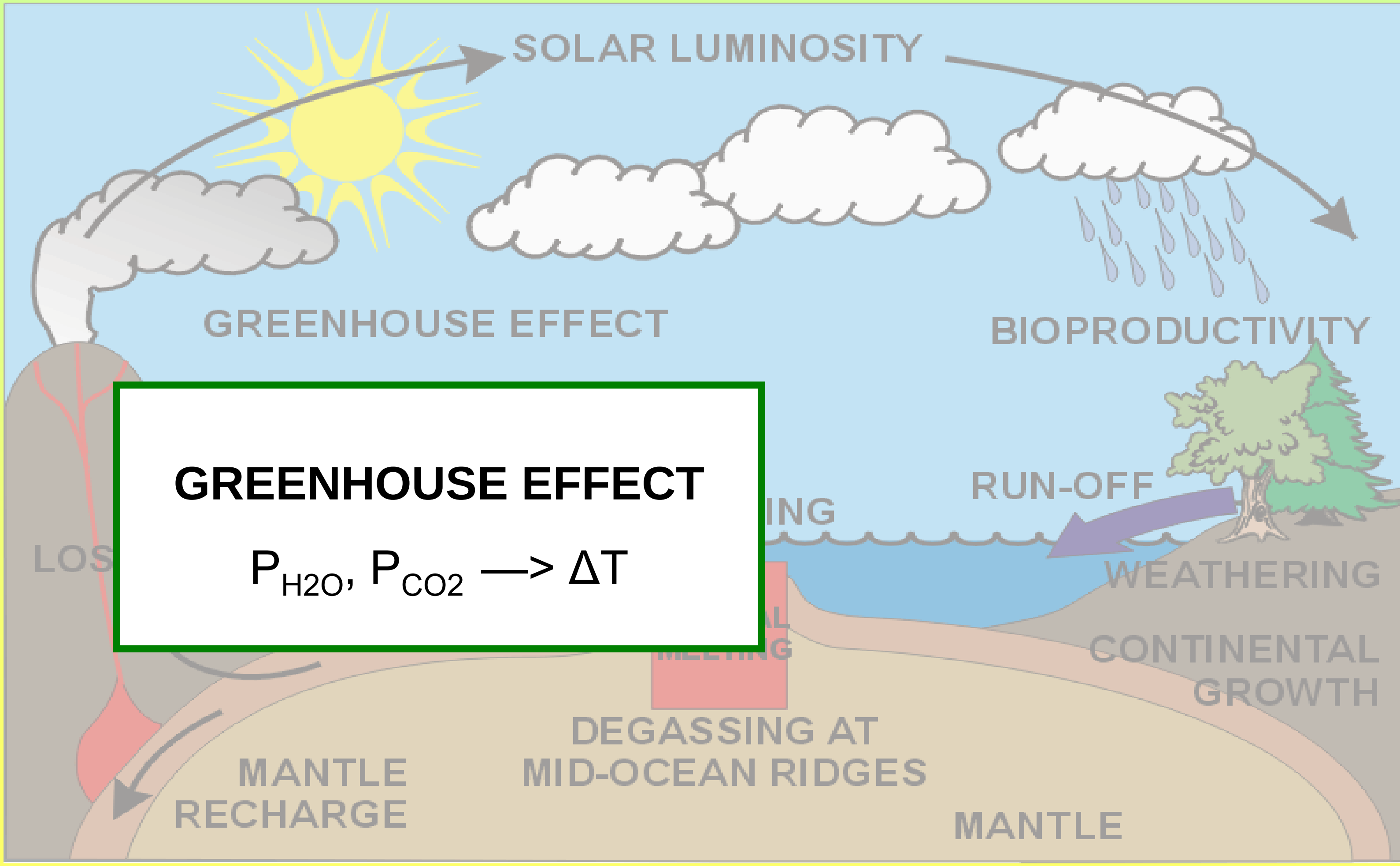


1. The global carbon cycle
2. Biosphere-geosphere interactions
3. The life span of the biosphere

THE GLOBAL CARBON CYCLE



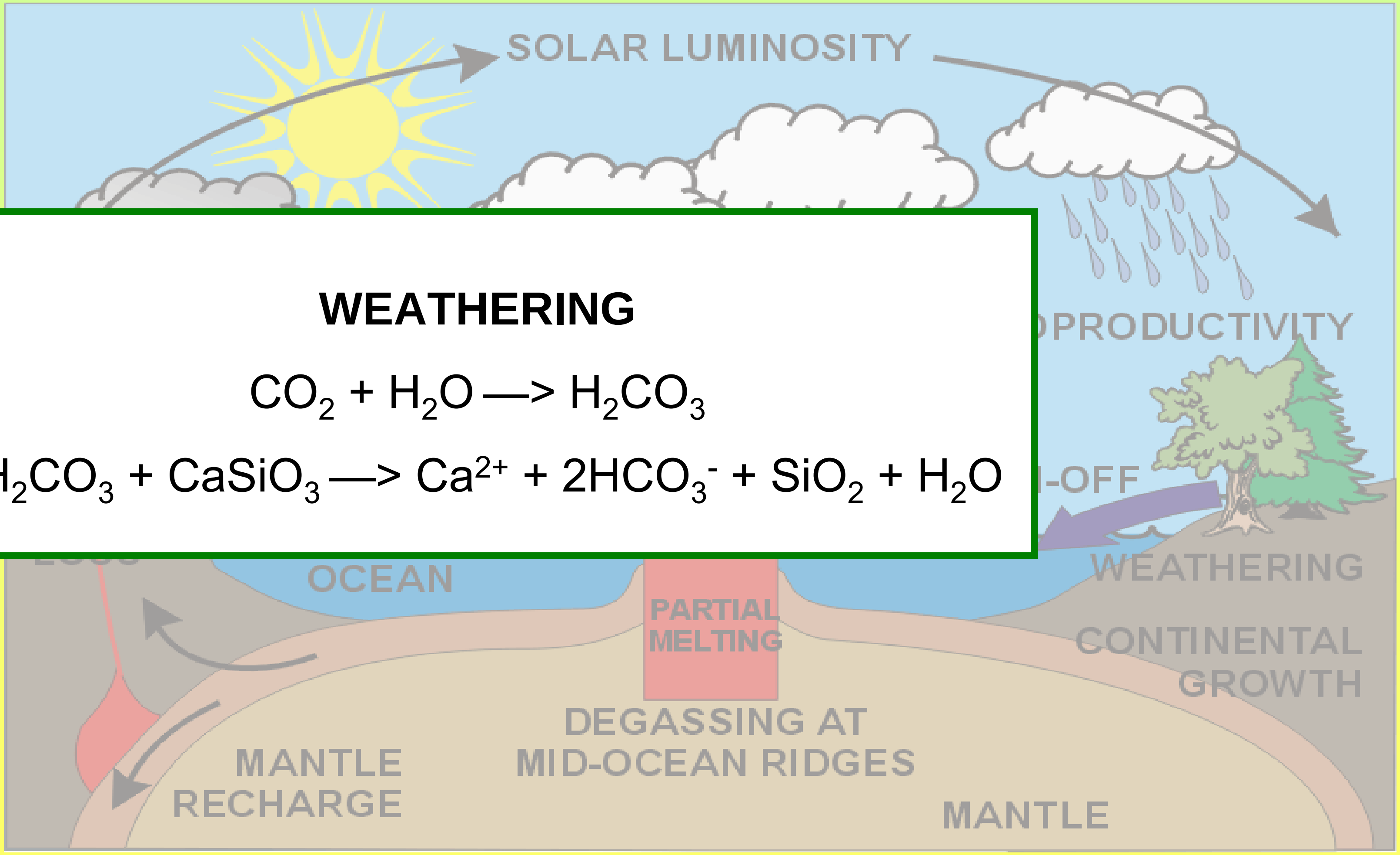
THE GLOBAL CARBON CYCLE



GREENHOUSE EFFECT

P_{H2O}, P_{CO2} —> ΔT

THE GLOBAL CARBON CYCLE

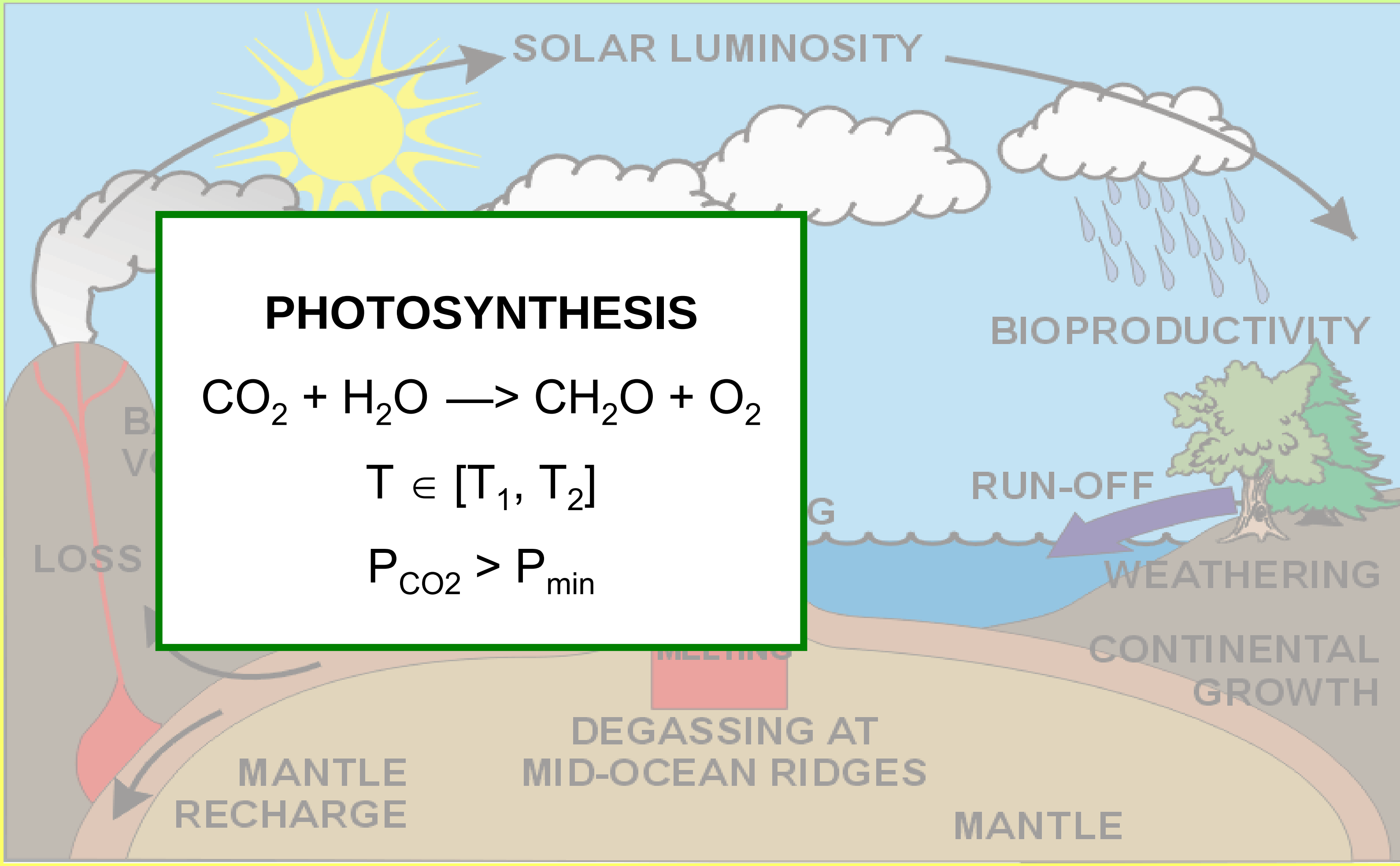


WEATHERING

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$2H_2CO_3 + CaSiO_3 \longrightarrow Ca^{2+} + 2HCO_3^- + SiO_2 + H_2O$$

THE GLOBAL CARBON CYCLE



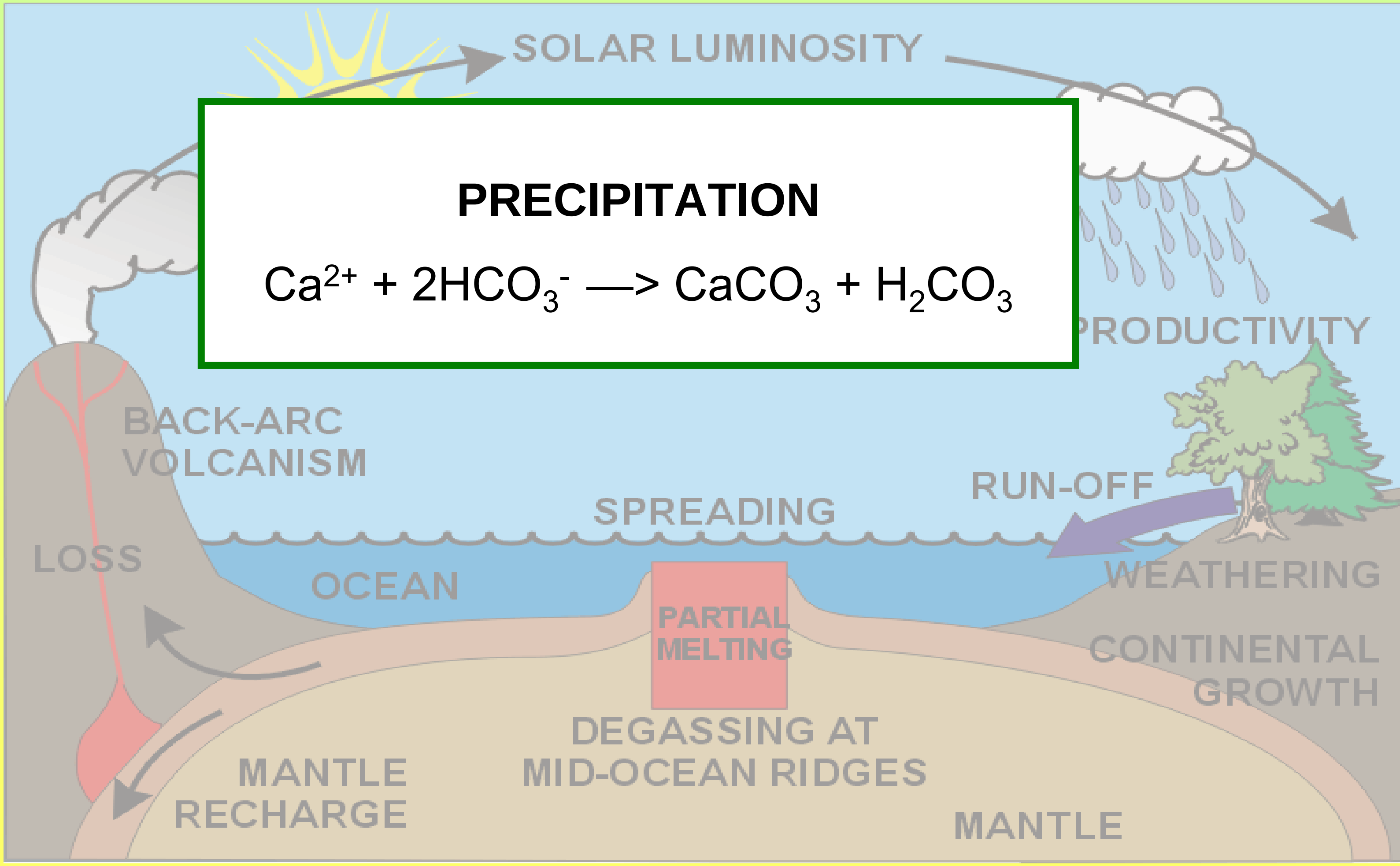
PHOTOSYNTHESIS

$$CO_2 + H_2O \longrightarrow CH_2O + O_2$$

$$T \in [T_1, T_2]$$

$$P_{CO2} > P_{min}$$

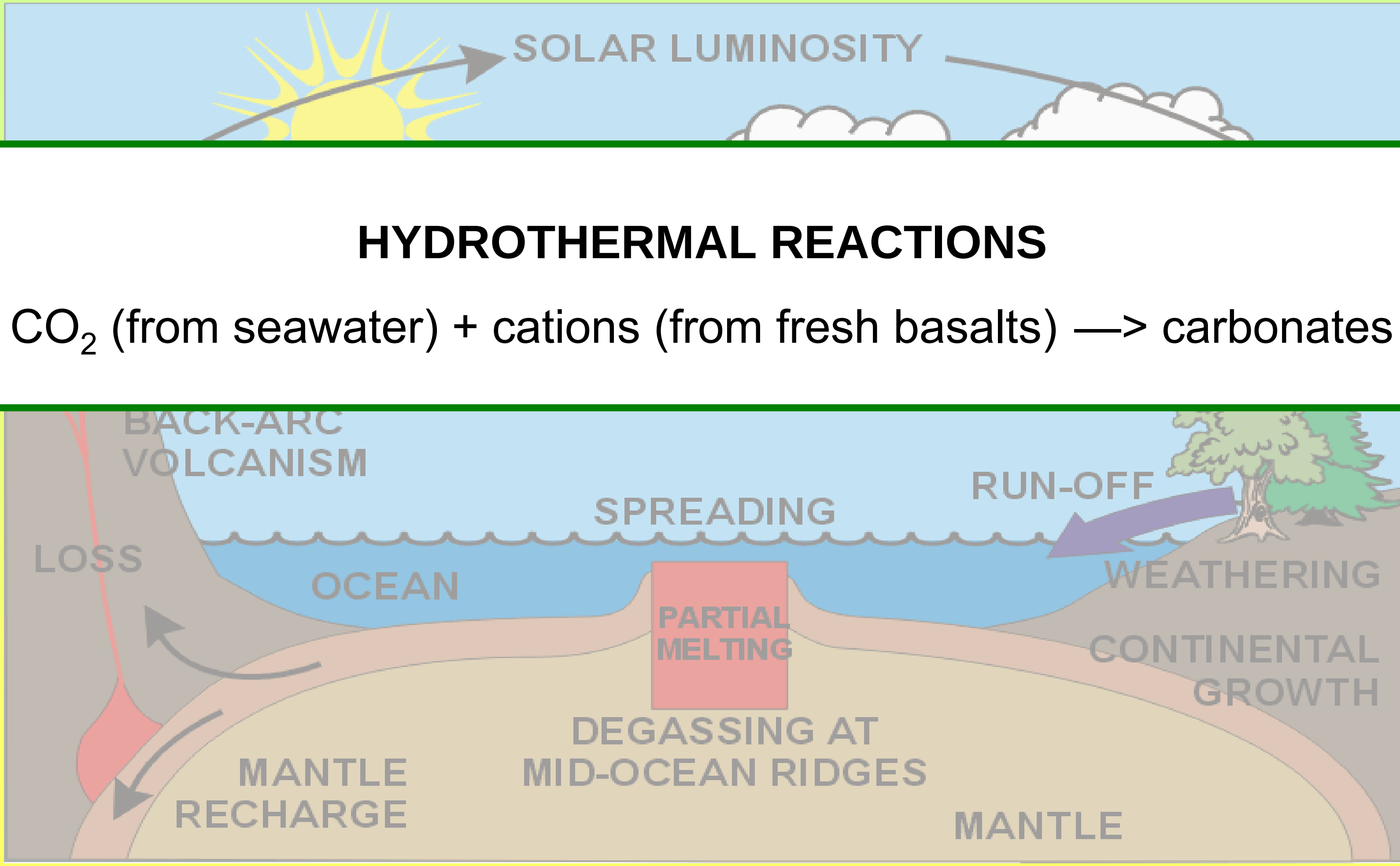
THE GLOBAL CARBON CYCLE



PRECIPITATION

$$Ca^{2+} + 2HCO_3^- \longrightarrow CaCO_3 + H_2CO_3$$

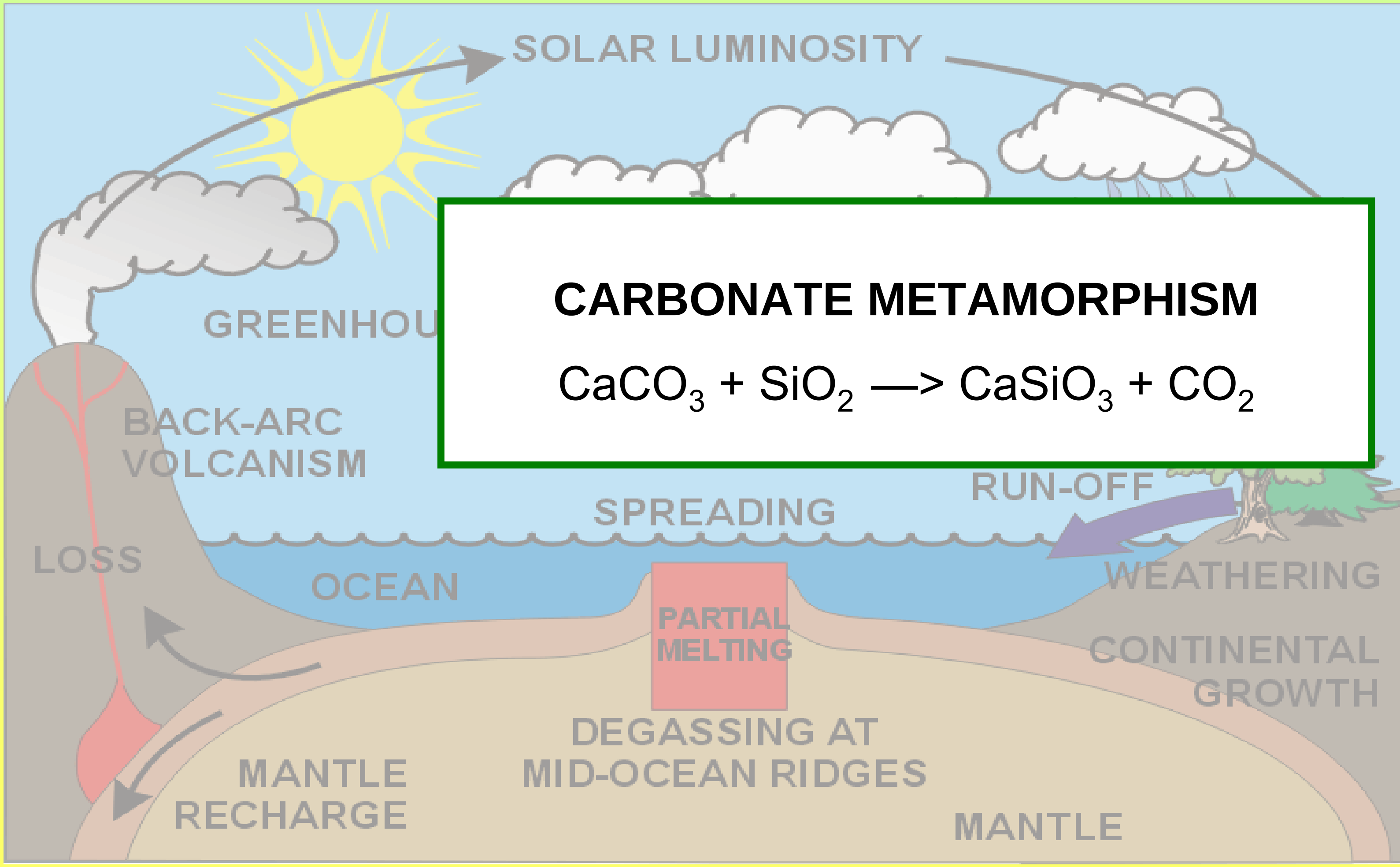
THE GLOBAL CARBON CYCLE



HYDROTHERMAL REACTIONS

CO_2 (from seawater) + cations (from fresh basalts) —> carbonates

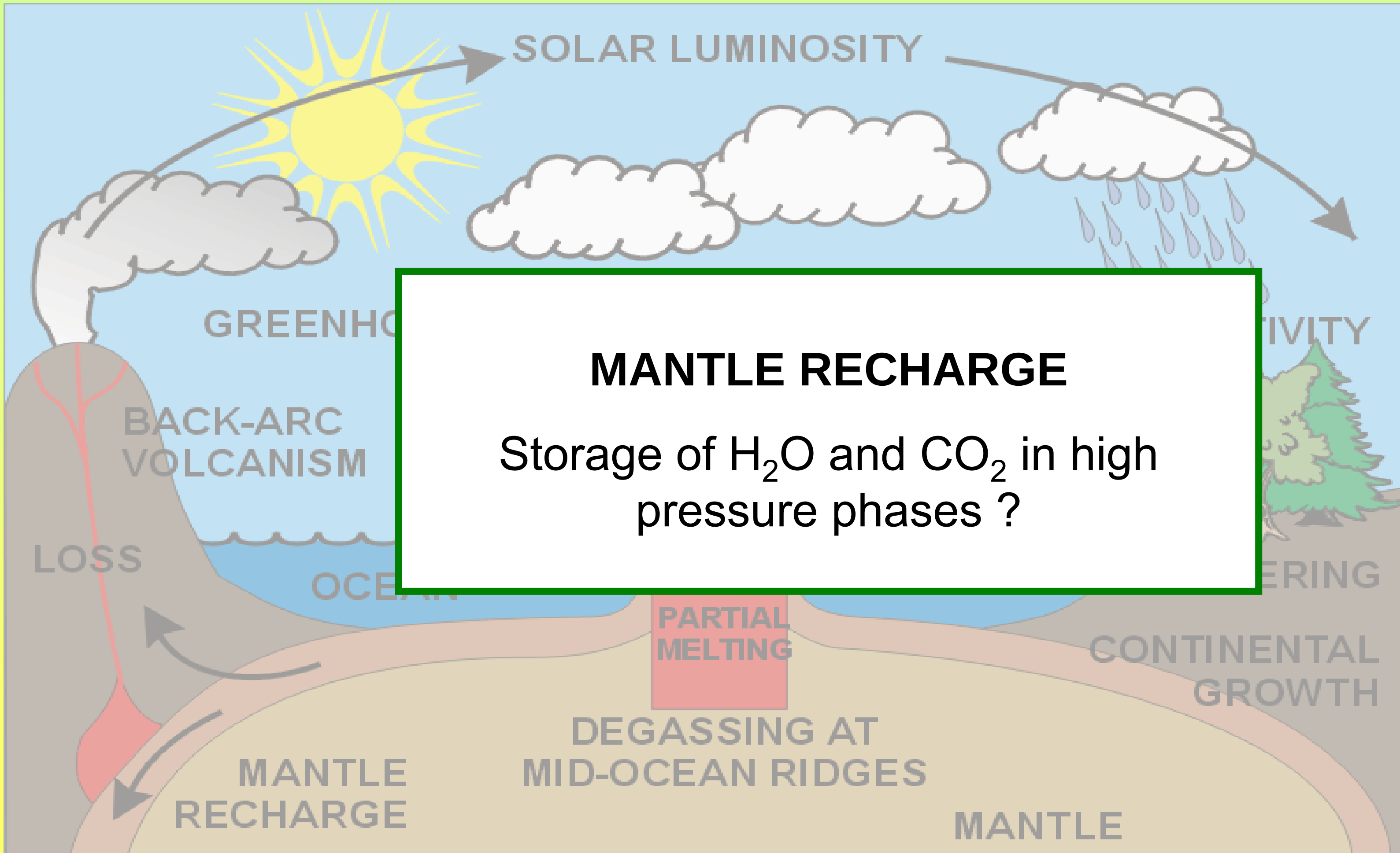
THE GLOBAL CARBON CYCLE



CARBONATE METAMORPHISM

$$CaCO_3 + SiO_2 \longrightarrow CaSiO_3 + CO_2$$

THE GLOBAL CARBON CYCLE



MANTLE RECHARGE

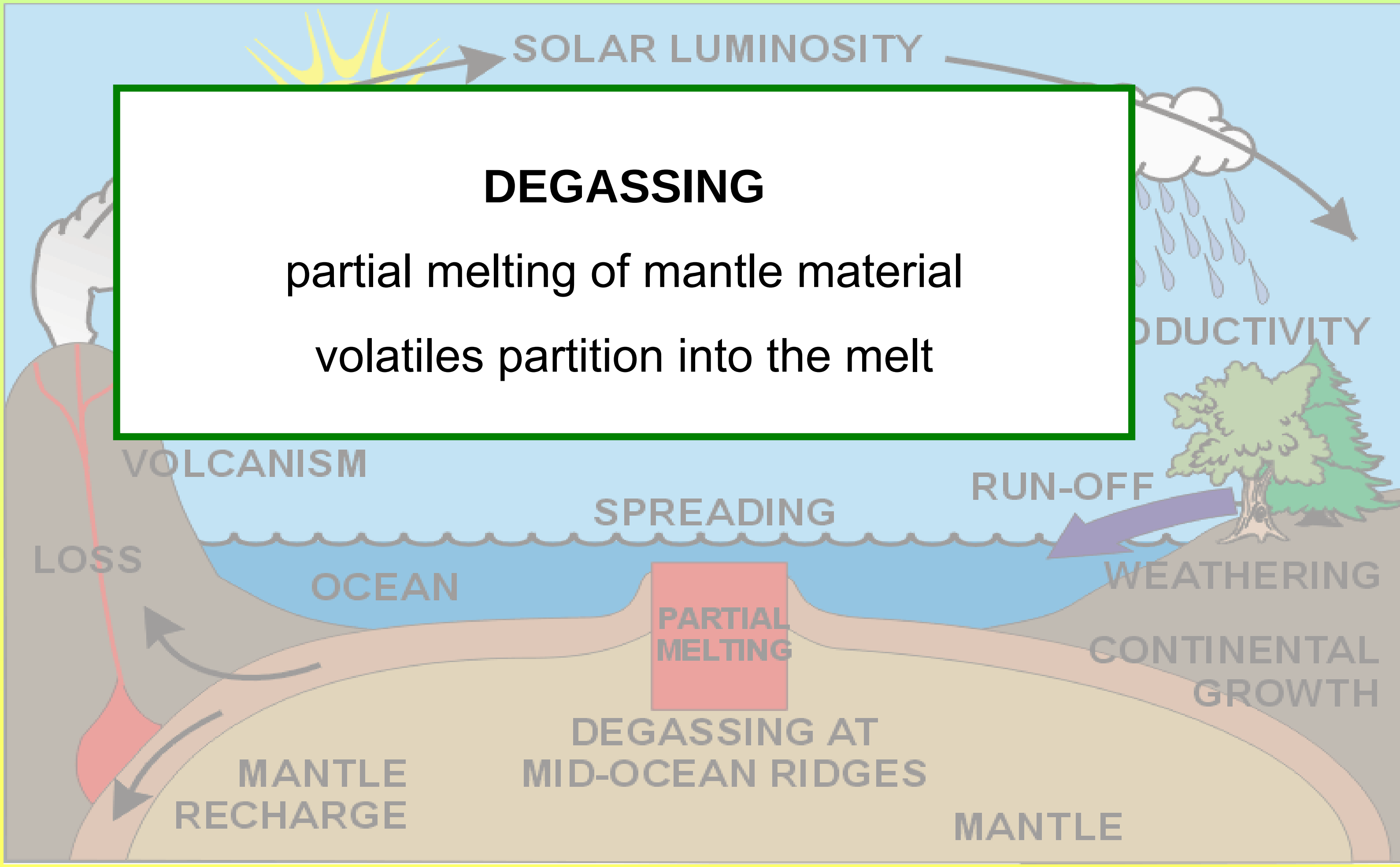
Storage of H_2O and CO_2 in high pressure phases ?

THE GLOBAL CARBON CYCLE

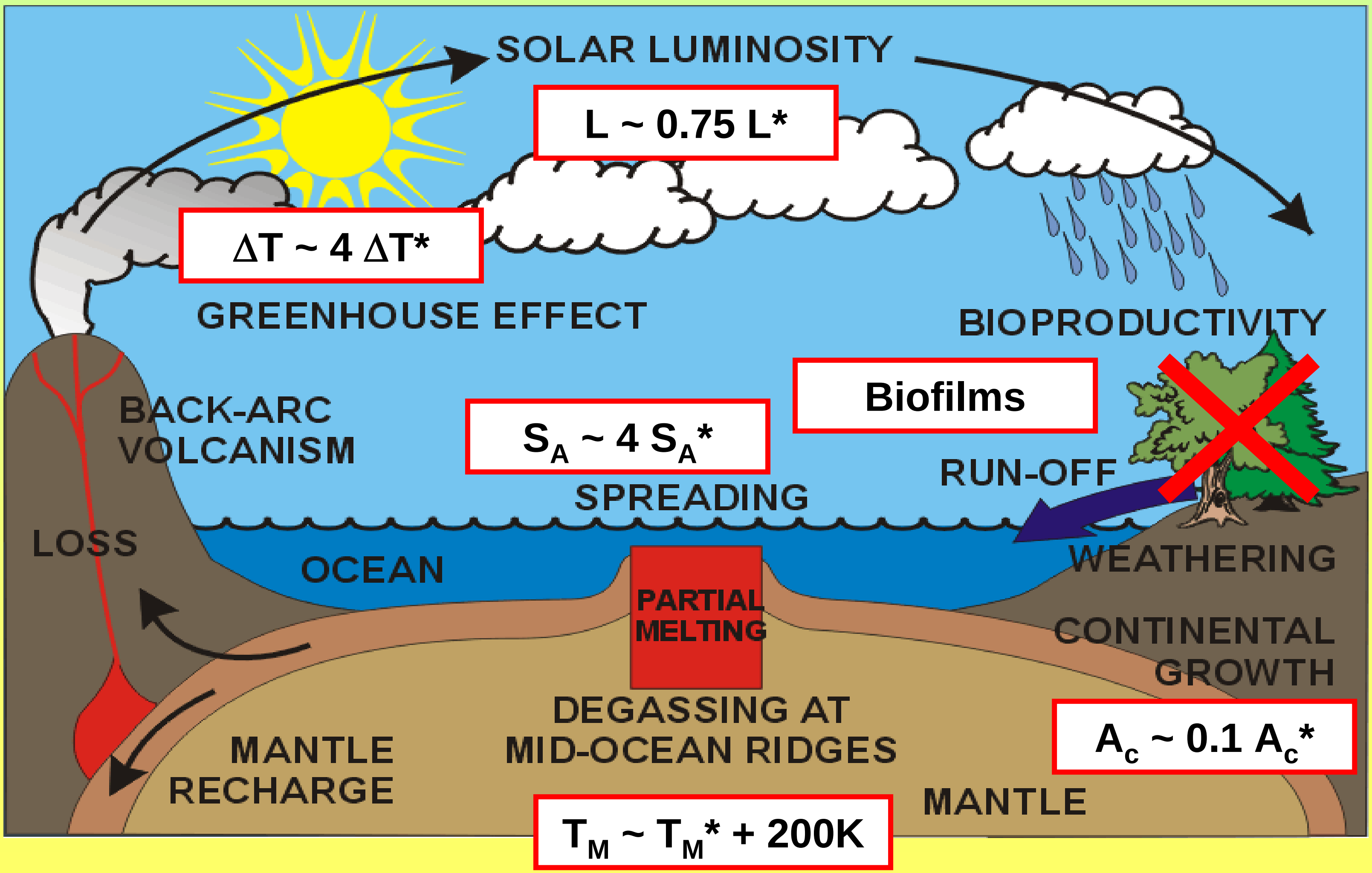
DEGASSING

partial melting of mantle material

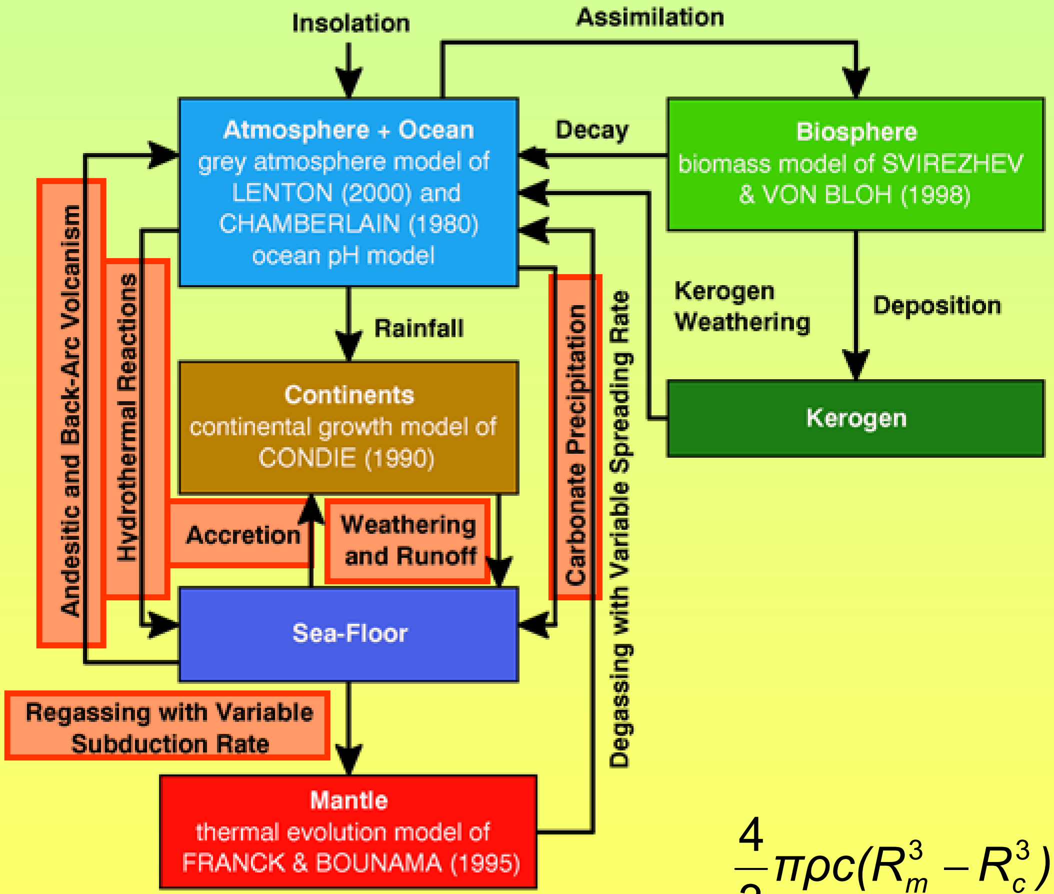
volatiles partition into the melt



THE ARCHAEAN GLOBAL CARBON CYCLE



MODEL DESCRIPTION



$$\dot{C}_m = \tau_f^{-1}(1-A)RC_f - S_A f_c d_m C_m / V_m$$

$$\dot{C}_{o+a} = \tau_f^{-1}(1-A)(1-R)C_f + S_A f_c d_m C_m / V_m + F_{\mathrm{weath}} + (1-\gamma)\tau_{\mathrm{bio}}^{-1} C_{\mathrm{bio}} + \tau_{\mathrm{ker}}^{-1} C_{\mathrm{ker}} - \Pi_{\mathrm{bio}} - F_{\mathrm{prec}} - F_{\mathrm{hyd}}$$

$$\dot{C}_c = \tau_f^{-1} A C_f - F_{\mathrm{weath}}$$

$$\dot{C}_f = F_{\mathrm{prec}} + F_{\mathrm{hyd}} - \tau_f^{-1} C_f$$

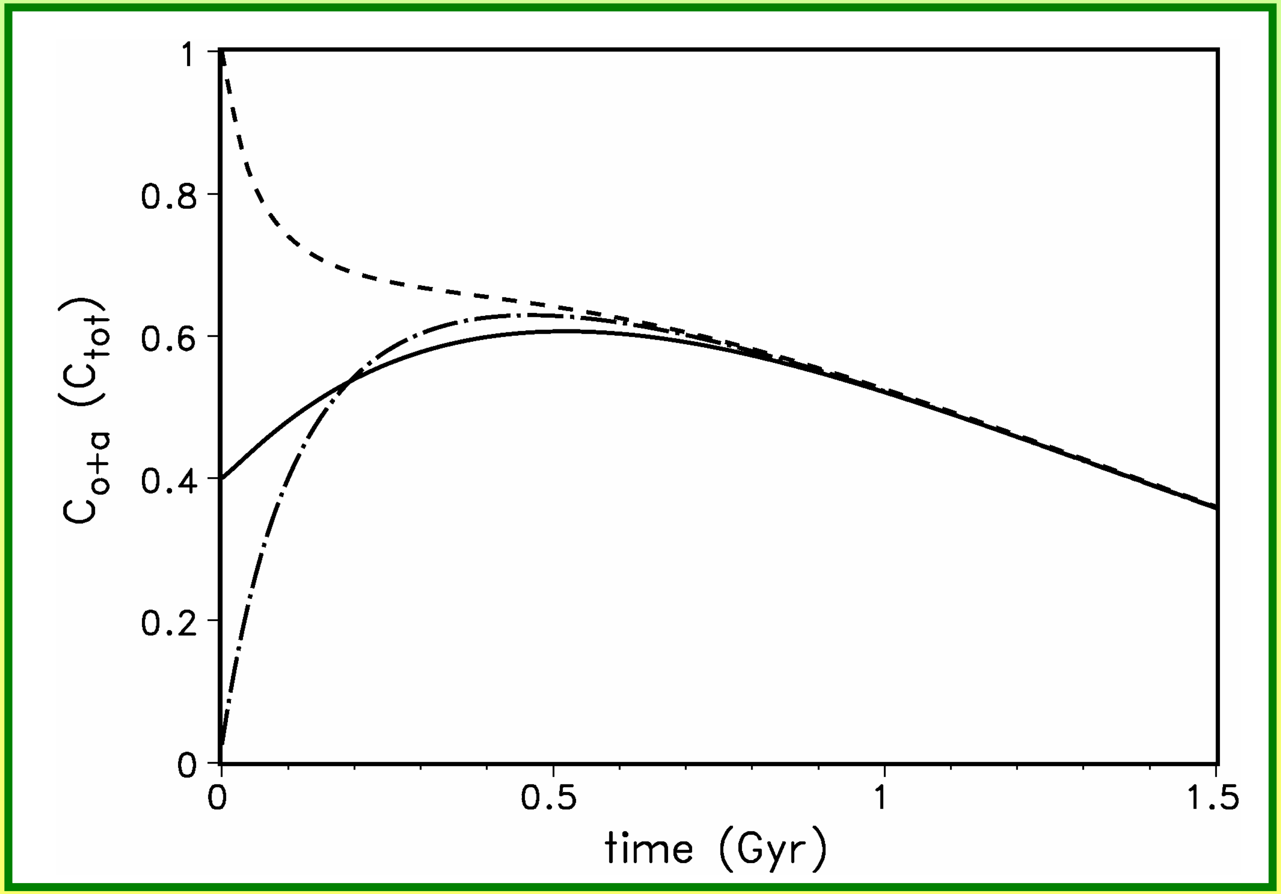
$$\dot{C}_{\mathrm{bio}} = \Pi_{\mathrm{bio}} - \tau_{\mathrm{bio}}^{-1} C_{\mathrm{bio}}$$

$$\dot{C}_{\mathrm{ker}} = \gamma \tau_{\mathrm{bio}}^{-1} C_{\mathrm{bio}} - \tau_{\mathrm{ker}}^{-1} C_{\mathrm{ker}}$$

$$\frac{4}{3}\pi\rho c(R_m^3 - R_c^3)\frac{\mathrm{d}T_m}{\mathrm{d}t} = -4\pi R_m^2 q_m + \frac{4}{3}\pi Q(R_m^3 - R_c^3)$$

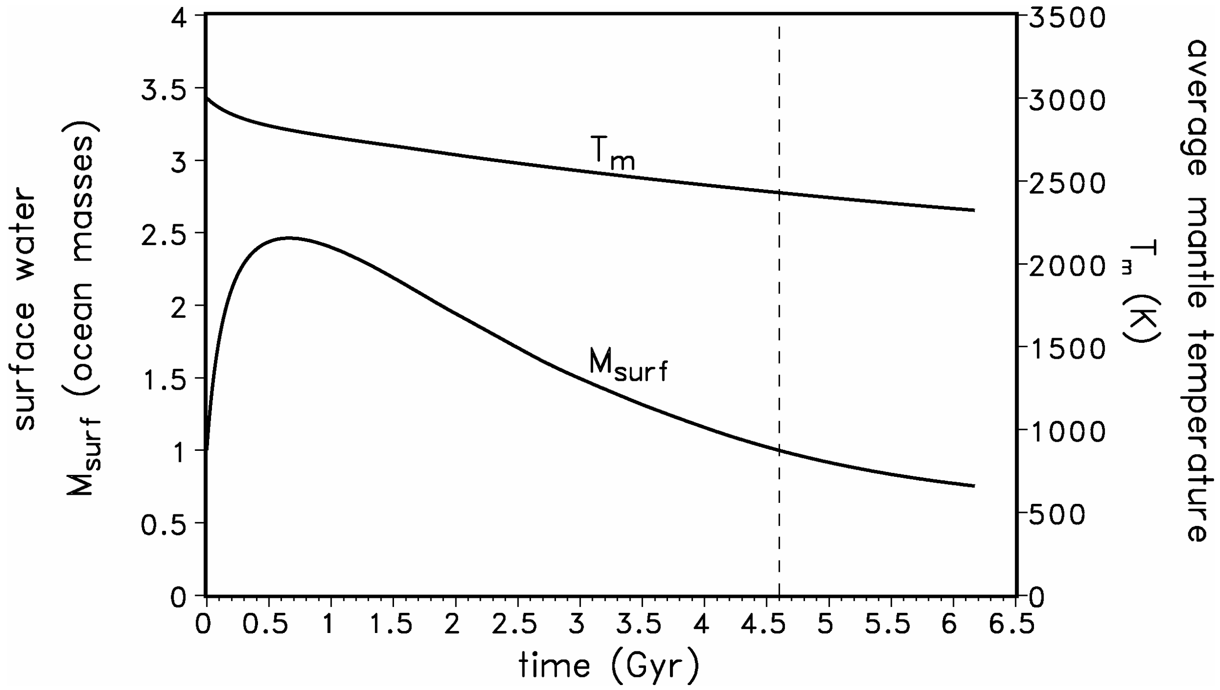
Franck et al. (2002), Tellus 54B, 325.

ADJUSTMENT



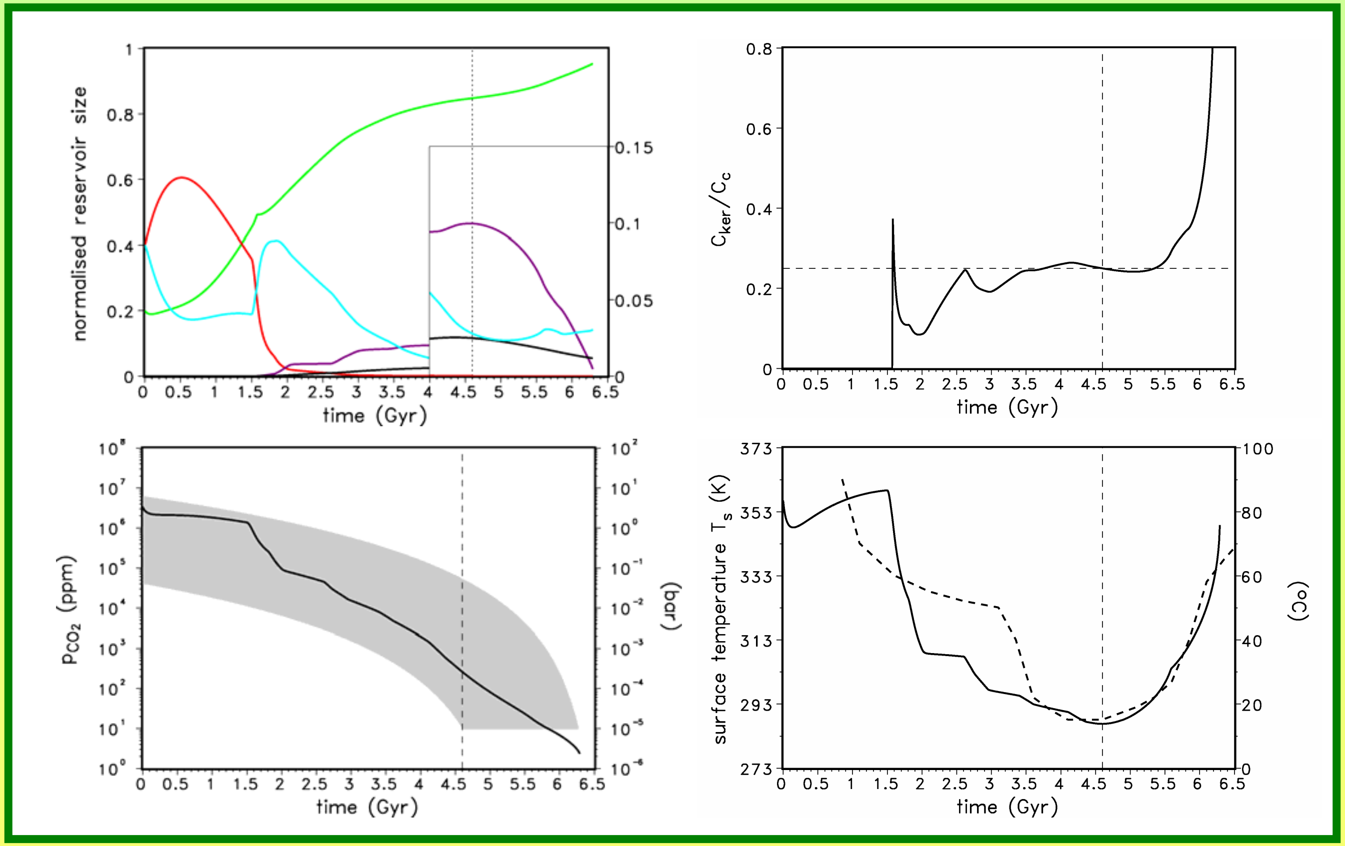
Evolution of the combined ocean and atmosphere reservoir C_{o+a} scaled to the total amount of carbon C_{tot} for various initial distributions of carbon between the pools. Note that after 1 Gyr the system has "forgotten" the initial conditions.

T_m and M_{surf}



Evolution of the average mantle temperature T_m and the surface water reservoir M_{surf} derived from the thermal evolution model.

RESULTS FOR CONSTANT HYDROTHERMAL FLUX

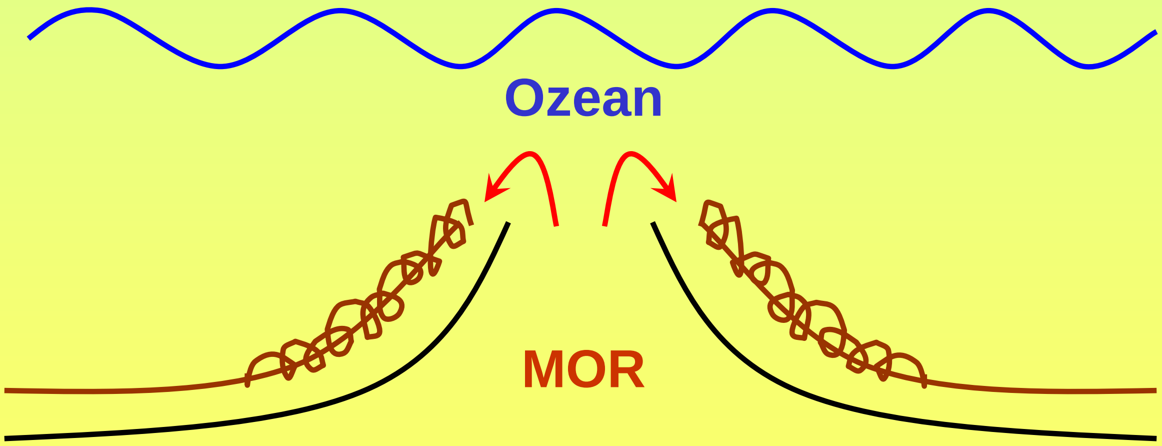


Model results for constant hydrothermal flux: (a) evolution of the reservoirs mantle (green), atmosphere + ocean (red), ocean floor (blue), kerogen (black), and continents (magenta), (b) evolution of the ratio C_{ker}/C_c where the horizontal dashed line indicates the observed ratio of 0.25, (c) evolution of atmospheric partial pressure of carbon dioxide pCO_2 where the grey shaded area represents values for non-vanishing biological productivity, and (d) evolution of the surface temperature T_s where the dashed line indicates the result of Schwartzman (1999).

HYDROTHERMAL CARBONISATION

= Reactions of „warm“ (ca. 20°C) water with fresh basalts of the oceanic crust where carbonates are formed

= CO_2 flux from the reservoir ocean+atmosphere to the reservoir oceanic crust



CO_2 from water + cations from basalts → carbonates

HYDROTHERMAL FLUXES

Parameterisation of hydrothermal fluxes F_{hyd}

1. F_{hyd} = constant

2. F_{hyd} □ *SR*

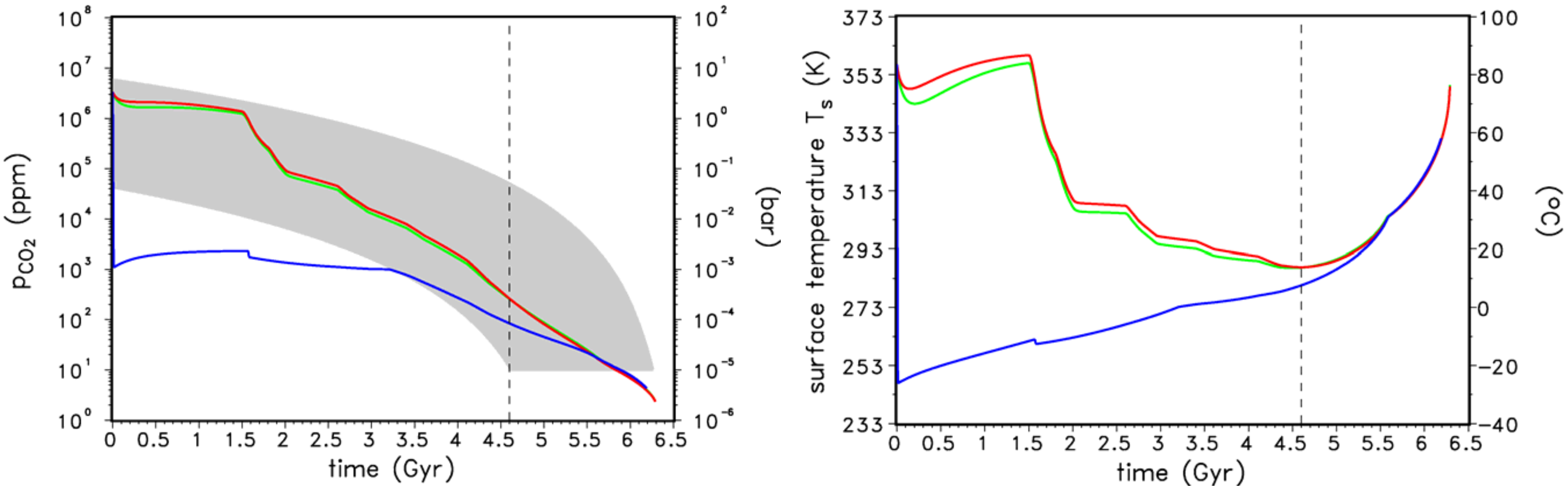
3. F_{hyd} □ *SR* □ pCO2 (Sleep and Zahnle, 2001)

where

SR: spreading rate

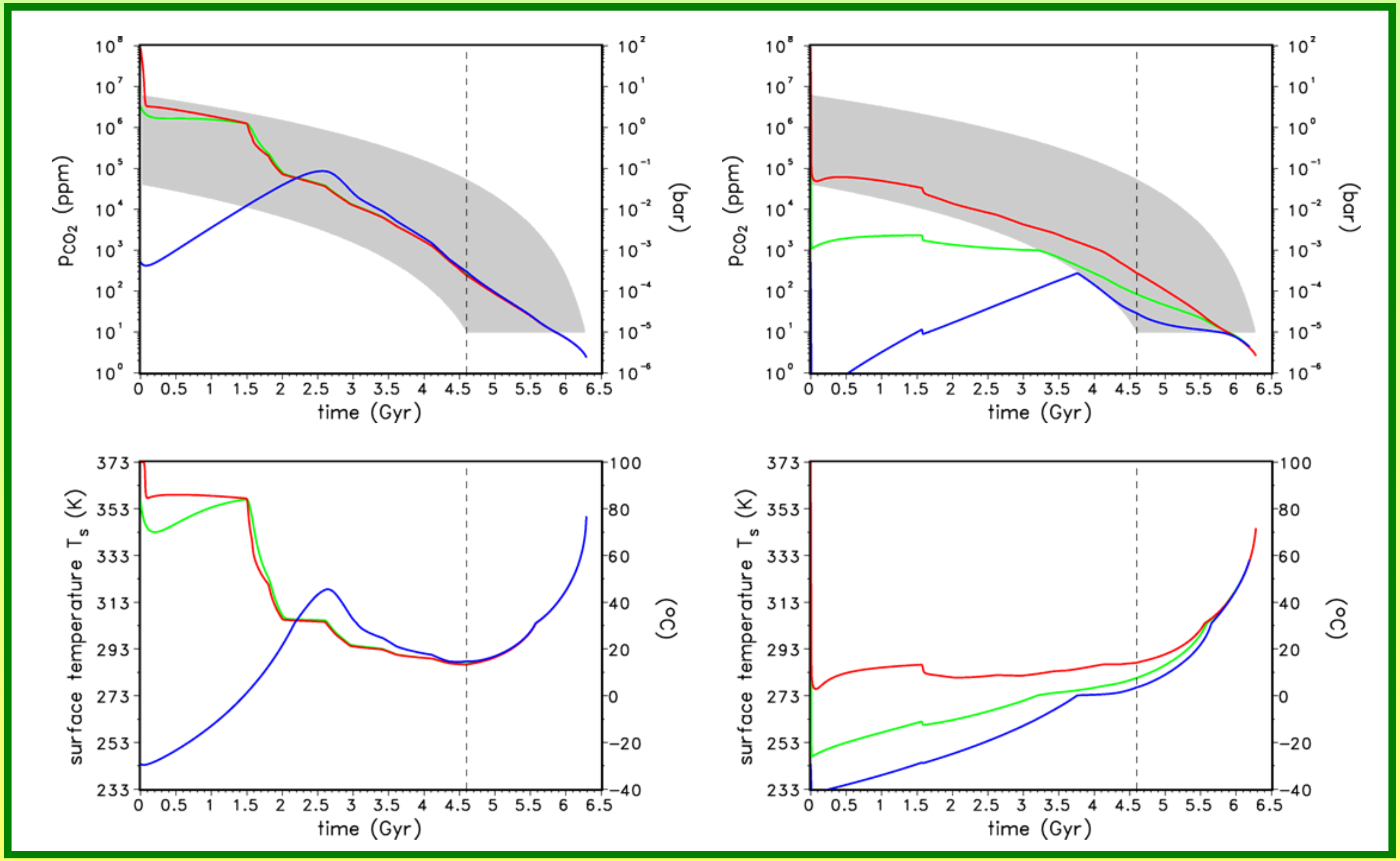
pCO_2: partial pressure of CO_2 in the ocean

3 PARAMETERISATIONS FOR F_{hyd}



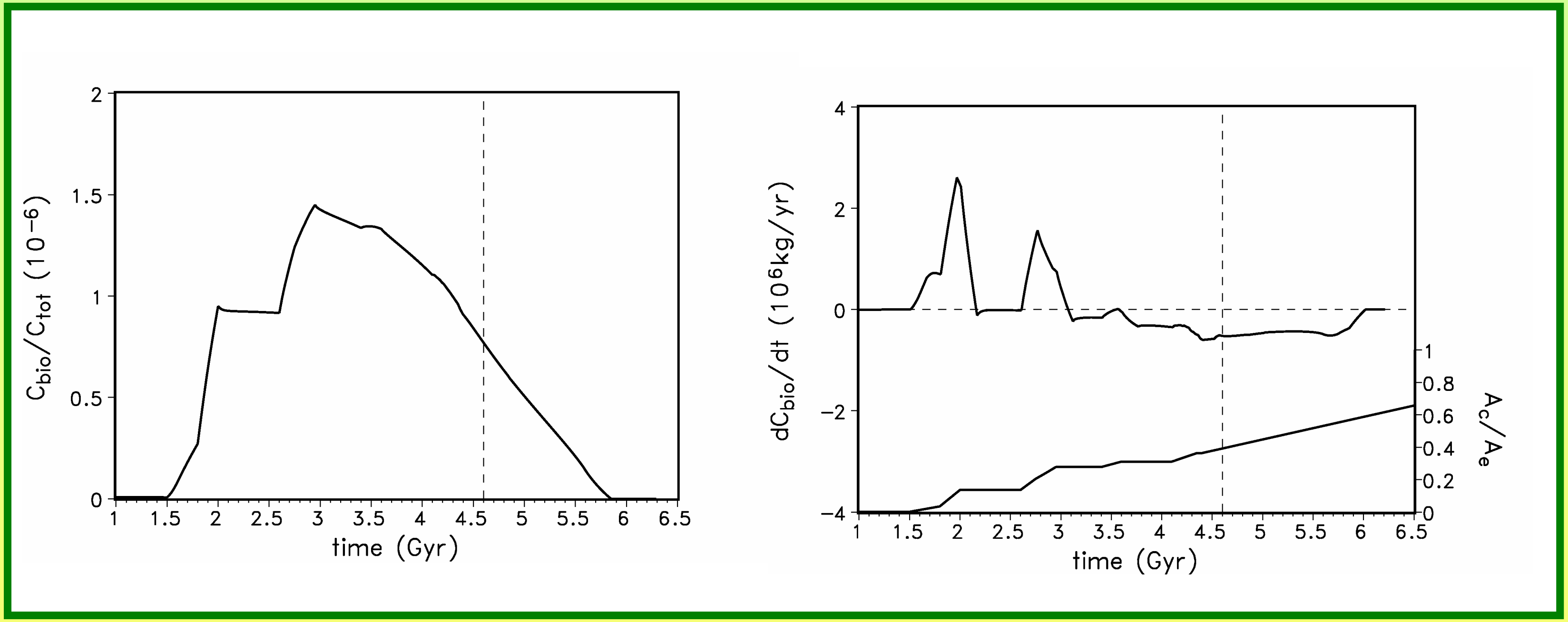
Evolution of atmospheric CO_2 partial pressure pCO_2 where the grey shaded area represents values for non-vanishing biological productivity (a) and surface temperature T_s (b) for three different parameterisations of the hydrothermal flux: constant (red), slow hydrothermal reaction kinetics (green), and fast hydrothermal reaction kinetics (blue).

pH MODELS



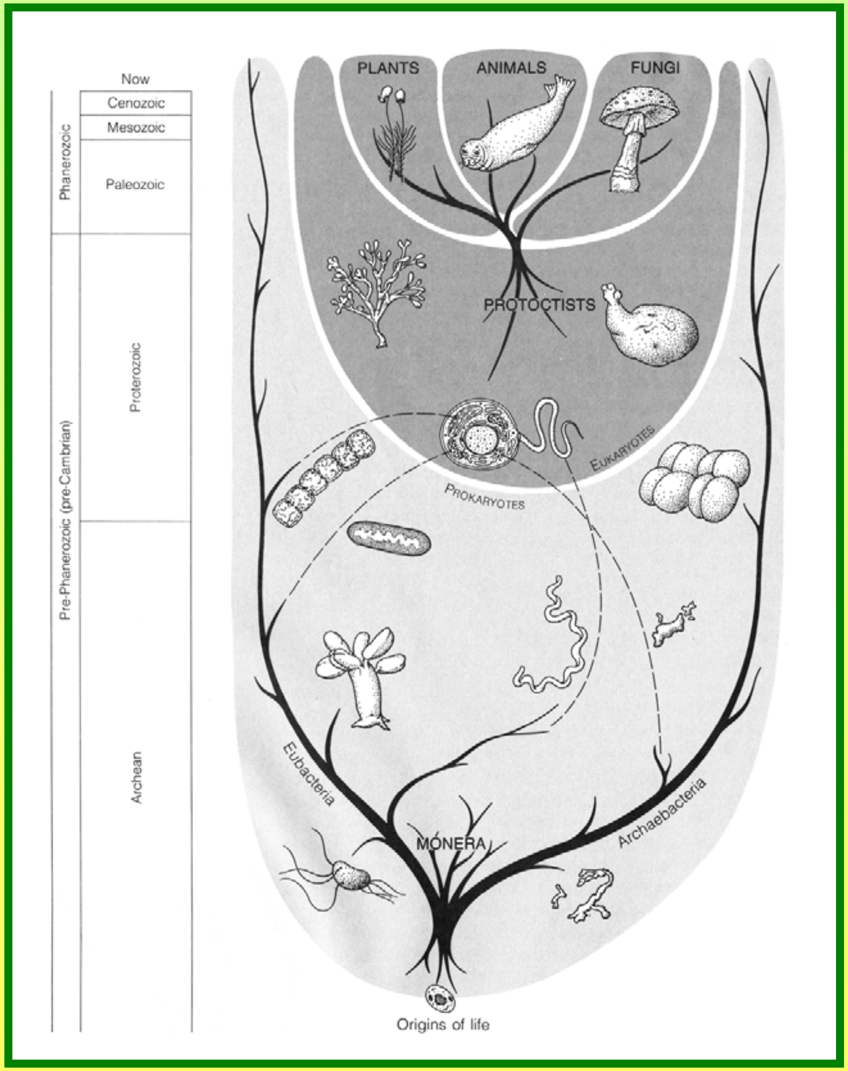
Evolution of atmospheric CO_2 partial pressure pCO_2 where the grey shaded area represents values for non-vanishing biological productivity (a,b) and surface temperature T_s (c,d) under the condition of slow hydrothermal reaction kinetics (a,c) and fast hydrothermal reaction kinetics (b,d) for three different ocean pH models: acid ocean model (red), constant pH (green), and soda ocean model (blue)..

THE BIOSPHERE POOL C_{bio}



Evolution of the biosphere pool C_{bio} (a) and its time derivative dC_{bio}/dt, (b) for slow hydrothermal reaction kinetics to emphasise changes in the biosphere pool. In order to demonstrate the correlation between the continental growth rate and changes in the biosphere pool the Condie model (Condie 1990) is displayed additionally in (b).

EVOLUTION OF BIOSPHERE



Symbiosis in cell evolution

Lynn Margulis (1993)

GEOSPHERE-BIOSPHERE FEEDBACKS

Biological productivity:

$$\Pi_{\mathrm{bio},i} = \Pi_{\max,i} \cdot \Pi_{T,i}(T) \cdot \Pi_{\mathrm{pCO}_2,i}(\mathrm{pCO}_2),\ i = 1,2,3$$

temperature tolerance windows		
i=1	procaryotes	[2°C,100°C]
i=2	eucaryotes	[5°C,45°C]
i=3	complex multicellular life	[0°C,30°C]

P I K

GEOSPHERE-BIOSPHERE FEEDBACKS

Biological enhancement of weathering:

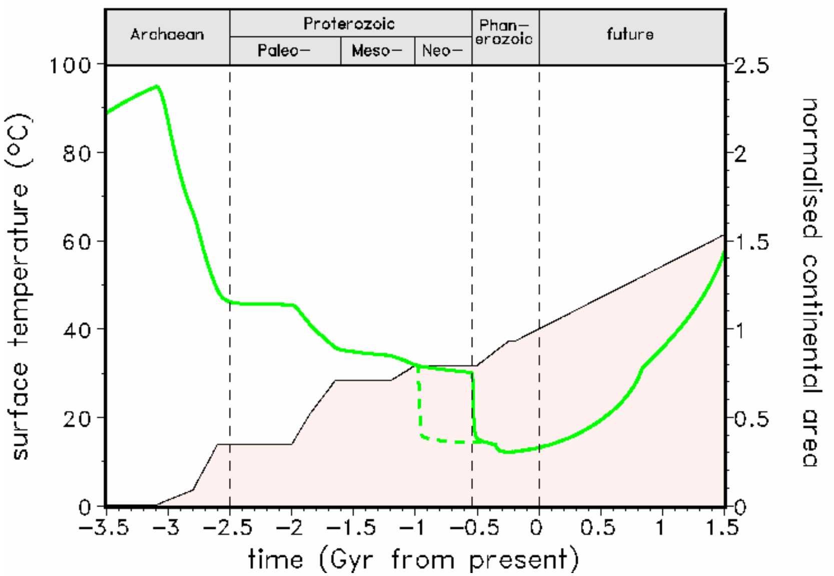
$$F_{\text{weath}} \propto \beta \cdot (a_{H^+})^{0.5} \cdot \exp \frac{T - T^*}{13.7\text{K}}$$

(Lenton and von Bloh, *GRL* 28 (9),1715, 2001)

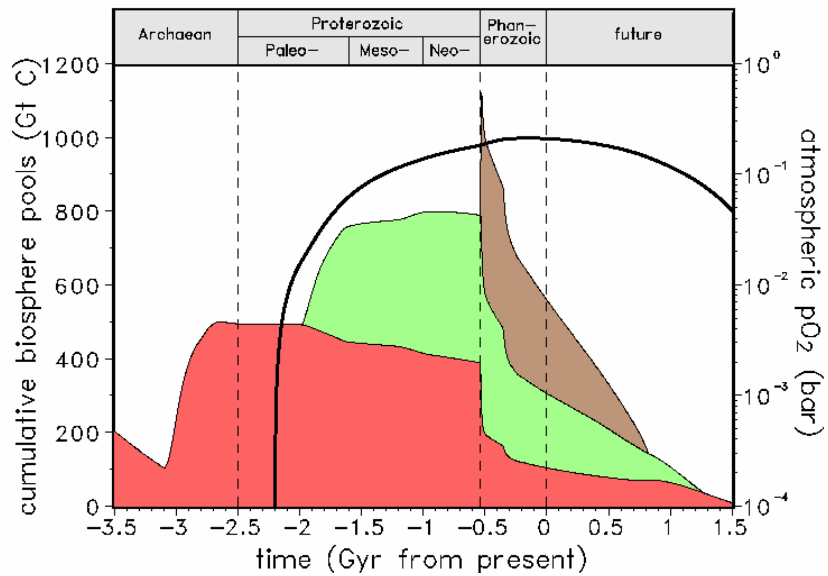
$$\beta = 1 - \sum_{i=1}^{3} \left(1 - \frac{1}{\beta_i}\right)\left(1 - \frac{\Pi_{\text{bio},i}}{\Pi^*_{\text{bio},1}}\right)$$

$$\beta_1 = \beta_2 = 1 \qquad \beta_3 = 3.6$$

THE CAMBRIAN EXPLOSION



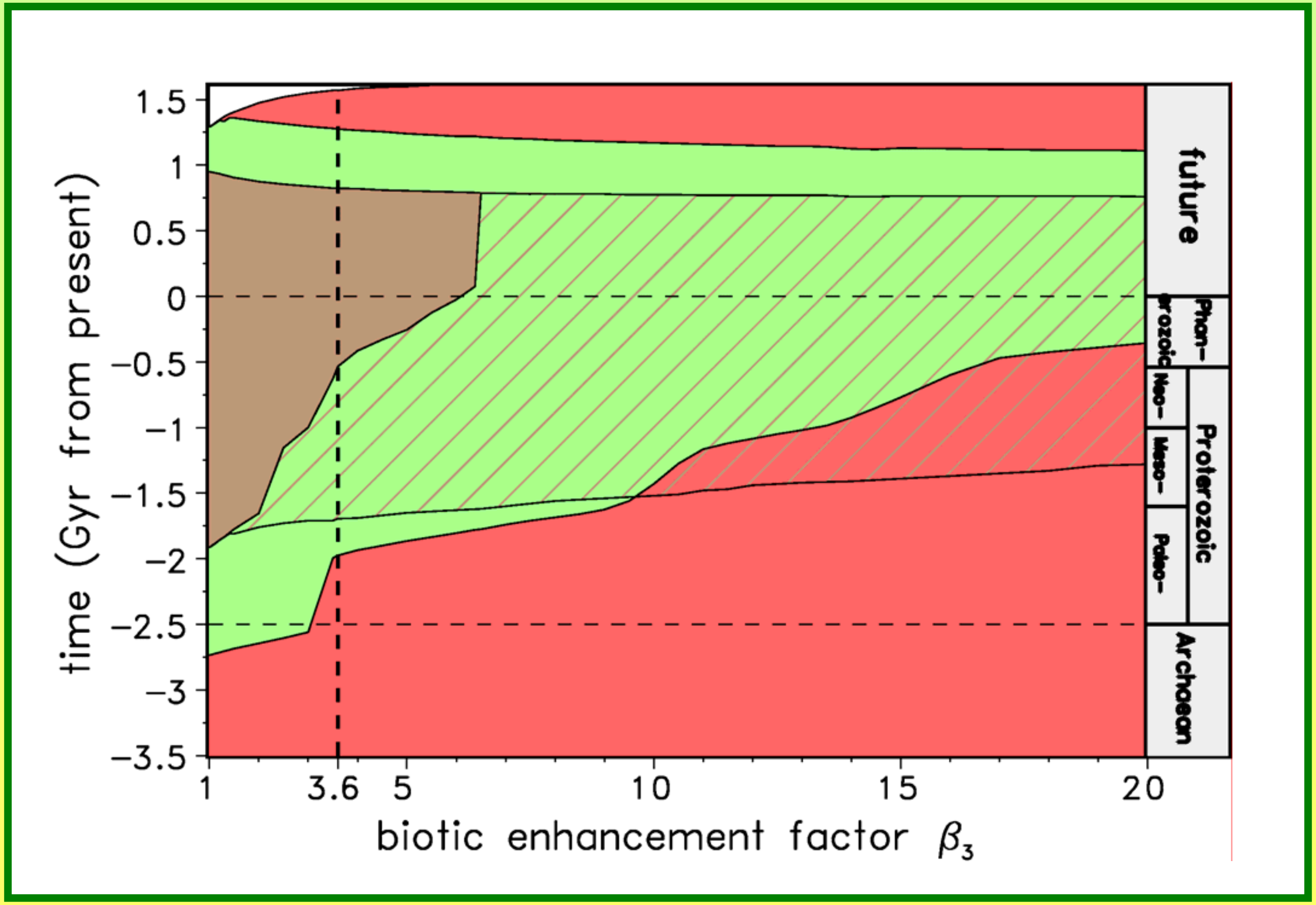
Evolution of global surface temperature.



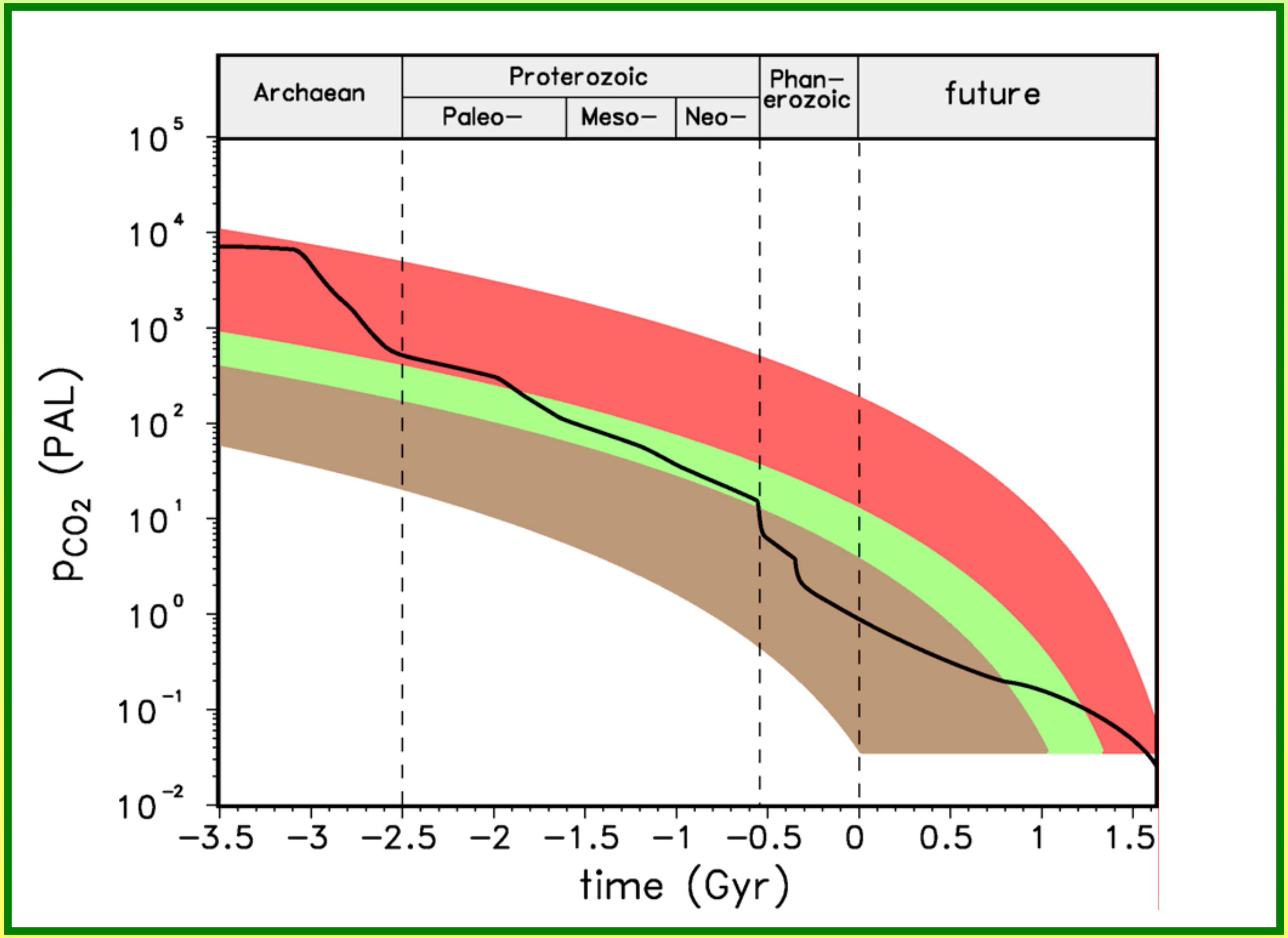
Evolution of the cumulative biosphere pools for procaryotes, eucaryotes, and complex multicellular life.

Von Bloh et al. (2003), GRL 30, 1963.

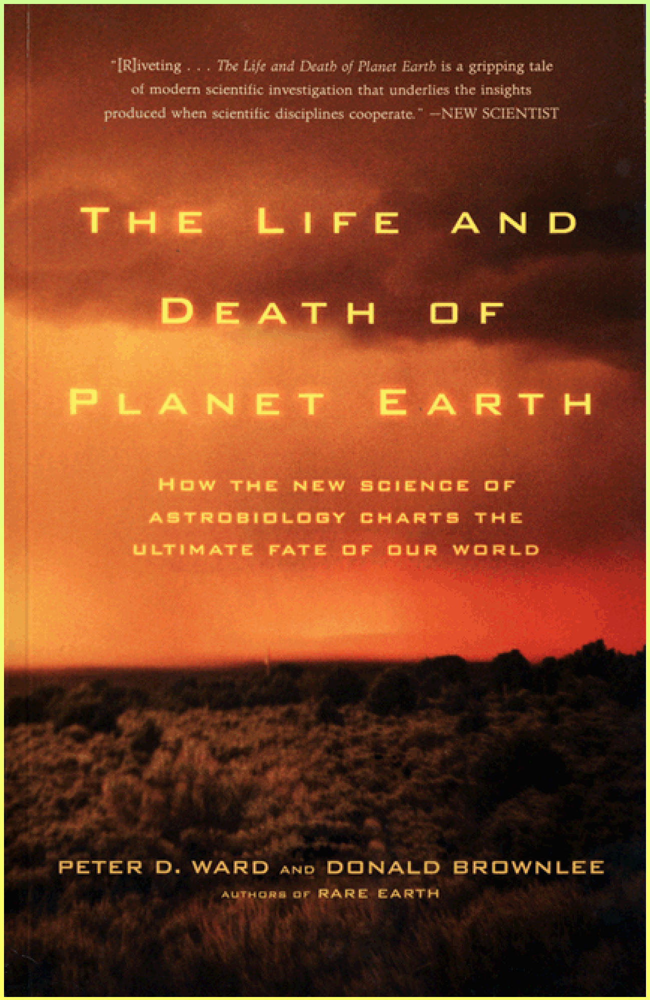
STABILITY DIAGRAM



TERRESTRIAL LIFE CORRIDOR (TLC)



Franck et al. (2006), Biogeosciences 3, 85.



- *The life and death of planet Earth* Peter Ward & Donald Brownlee 2002

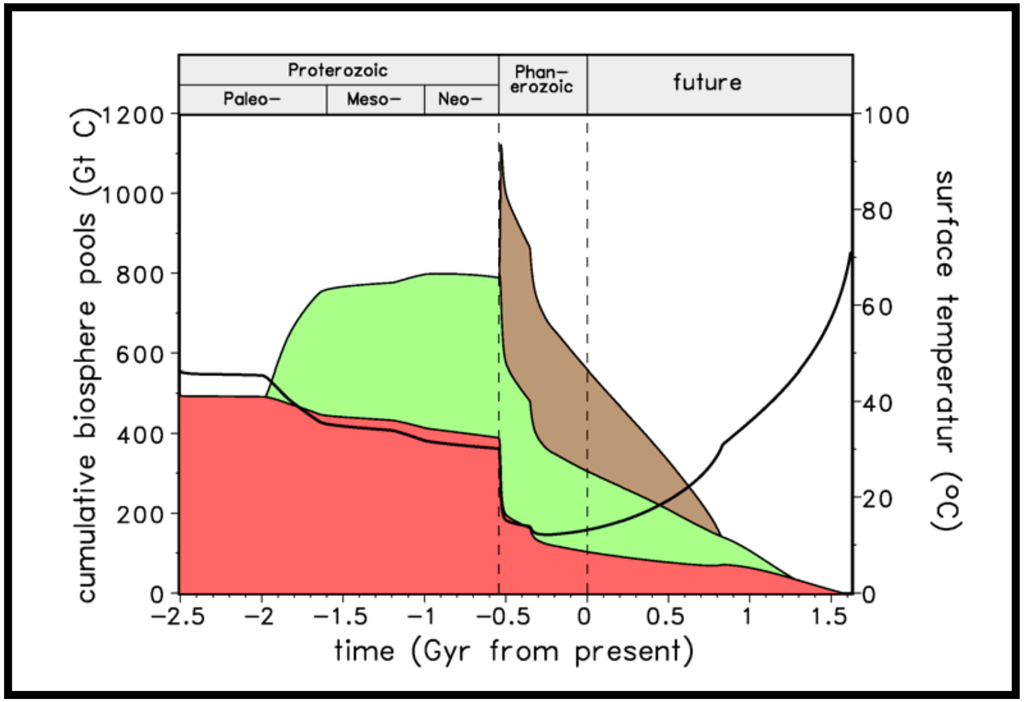

THE END ?

Planetary Engineering

Definition: Planetary engineering is the application of *technology* for the purpose of influencing the global properties of a planet (Fogg, 1995). It is a generalization of the *geoengineering* approach, which investigates modifications of Earth‘s environment on a global scale to avoid dangerous developments for humankind.

Here: Extending the life span of complex life forms on Earth

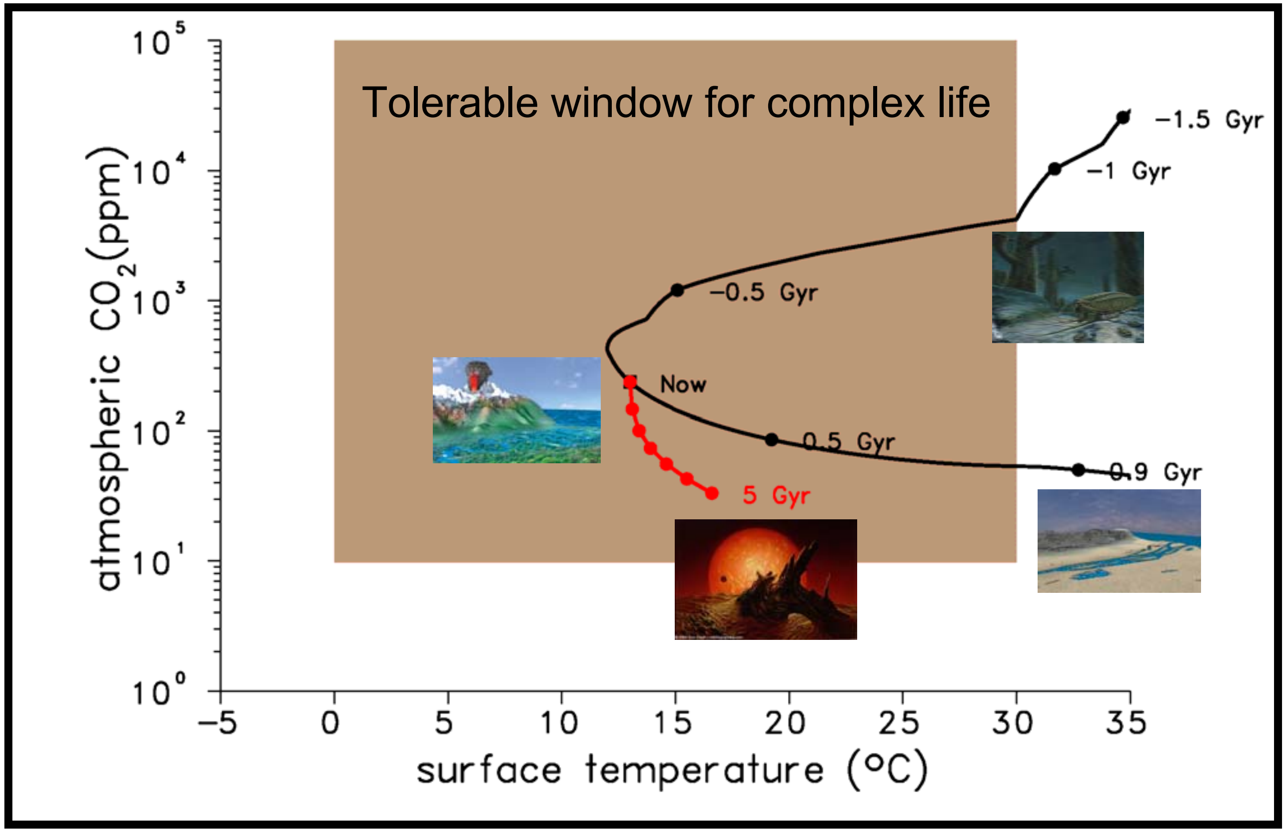
Causes and timing of future biosphere extinctions



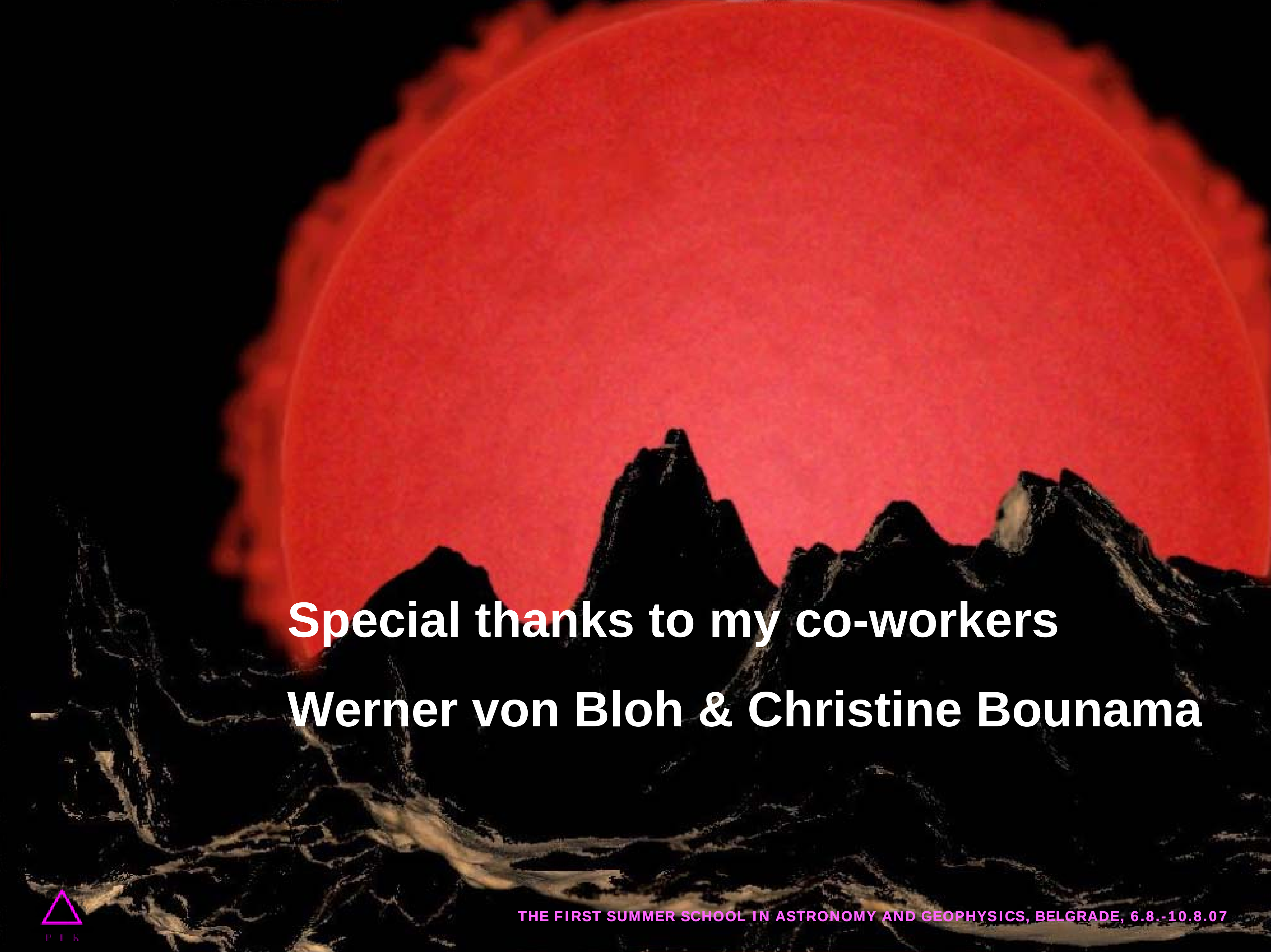
S. Franck, C. Bounama, W. von Bloh, *Biogeosciences*, 2006

Biosphere type	Temperature tolerance	CO_2 tolerance	Biotic enhancement of weathering
Procaryotes	[5°C,100°C]	[10,∞] ppm	1
Eucaryotes (protista)	[2°C,45°C]	[10,∞] ppm	1
Complex life	[0°C,30°C]	[10,∞] ppm	3.6

Terrestrial Life Corridor (TLC)



TLC defines guardrails for temperature and CO_2


Special thanks to my co-workers
Werner von Bloh & Christine Bounama