Colonization of the terrestrial environment *in silico*

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+ 'T' Davies-Barnard, Paul Valdes (University of Bristol)
+ Ryan Pavlick (JPL)

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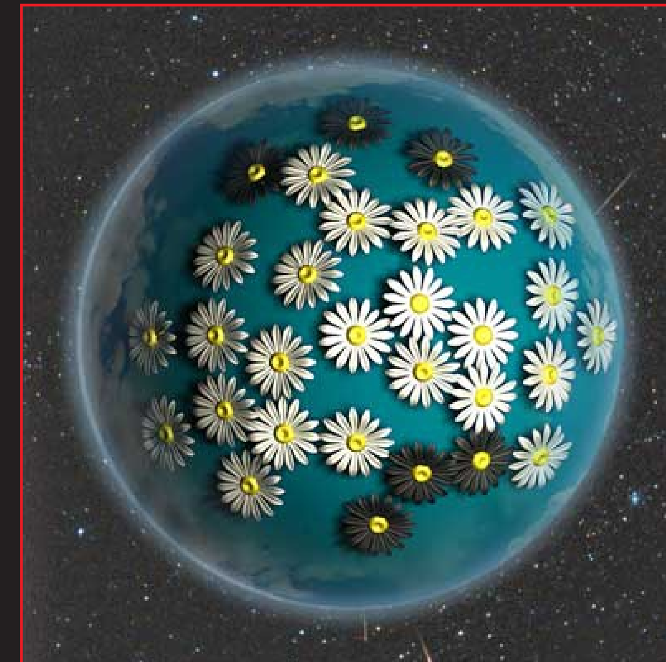
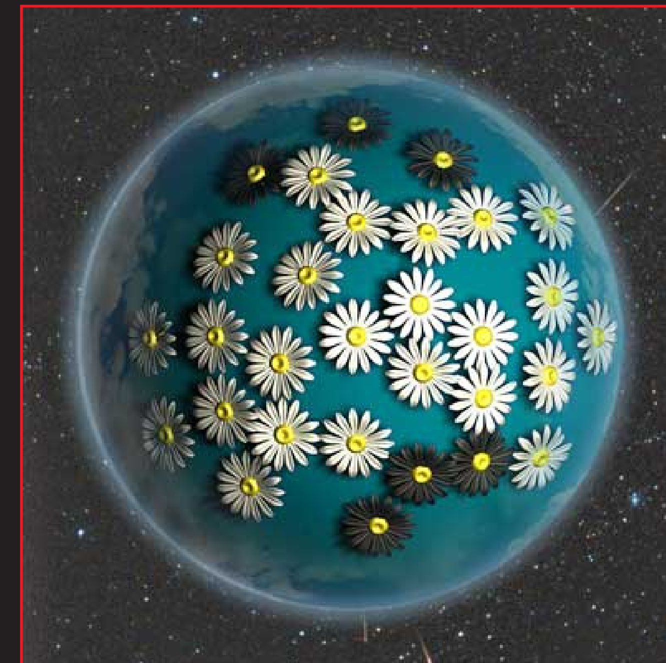
Long-term regulation & evolution of global climate

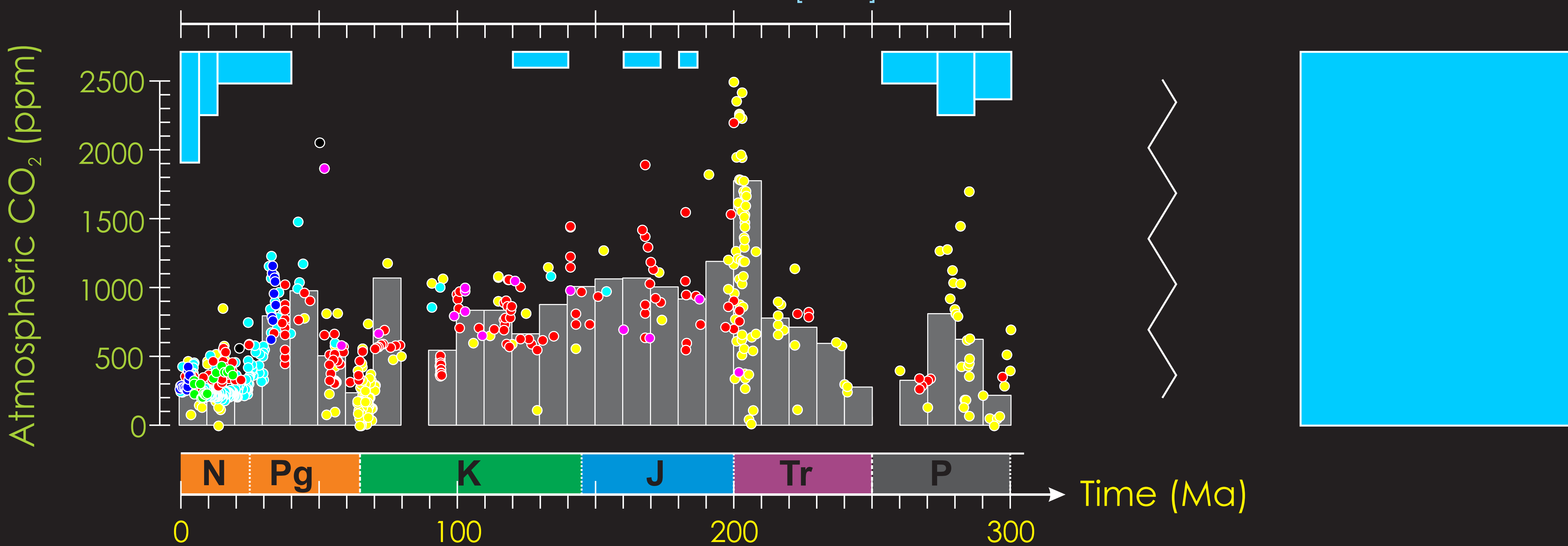


Long-term regulation & evolution of global climate

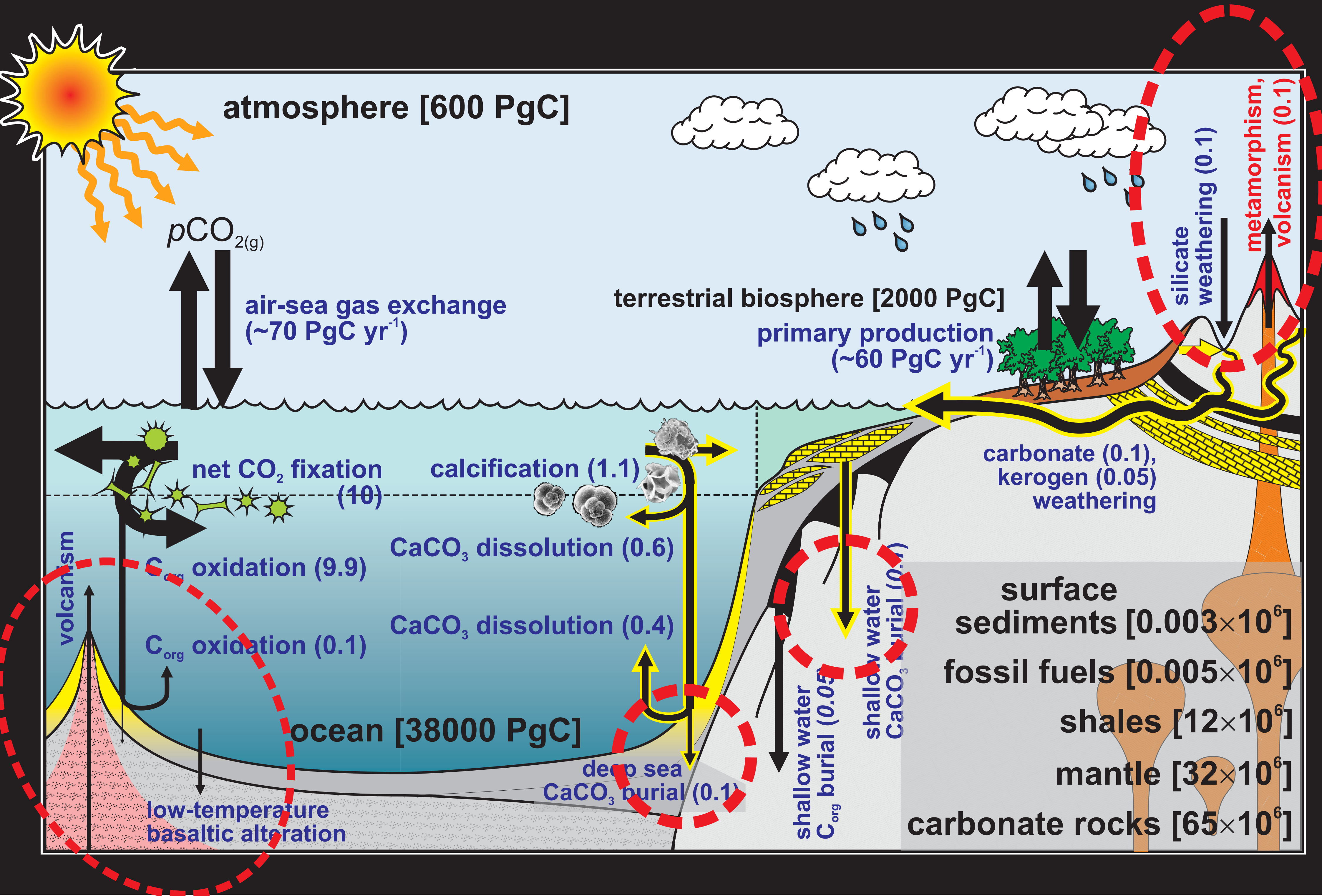


From: *Hönisch et al.* [2012]

Occurrence of
ice ages (relative intensity)
source; *Crowell* [1999]



Long-term regulation & evolution of global climate



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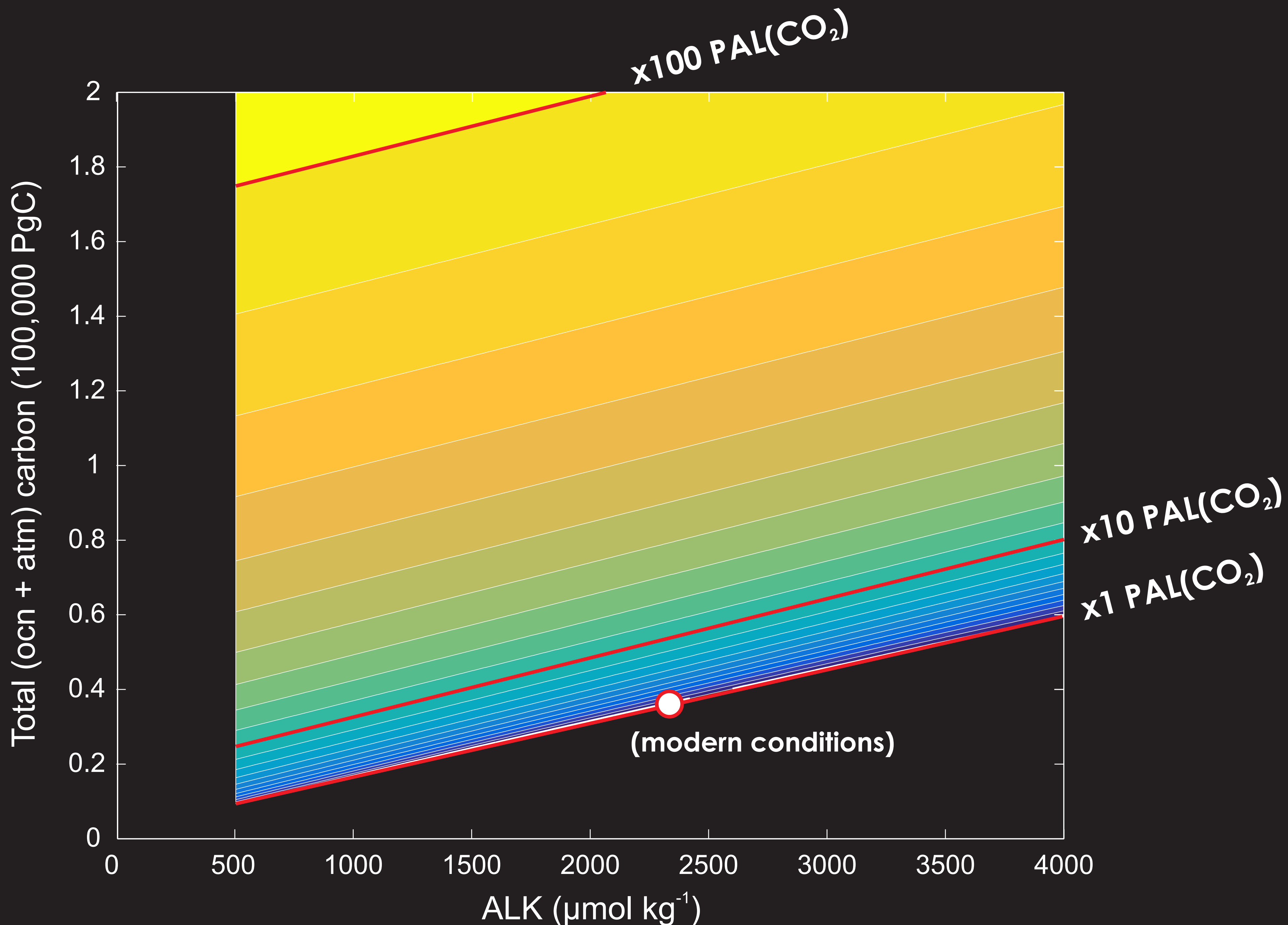
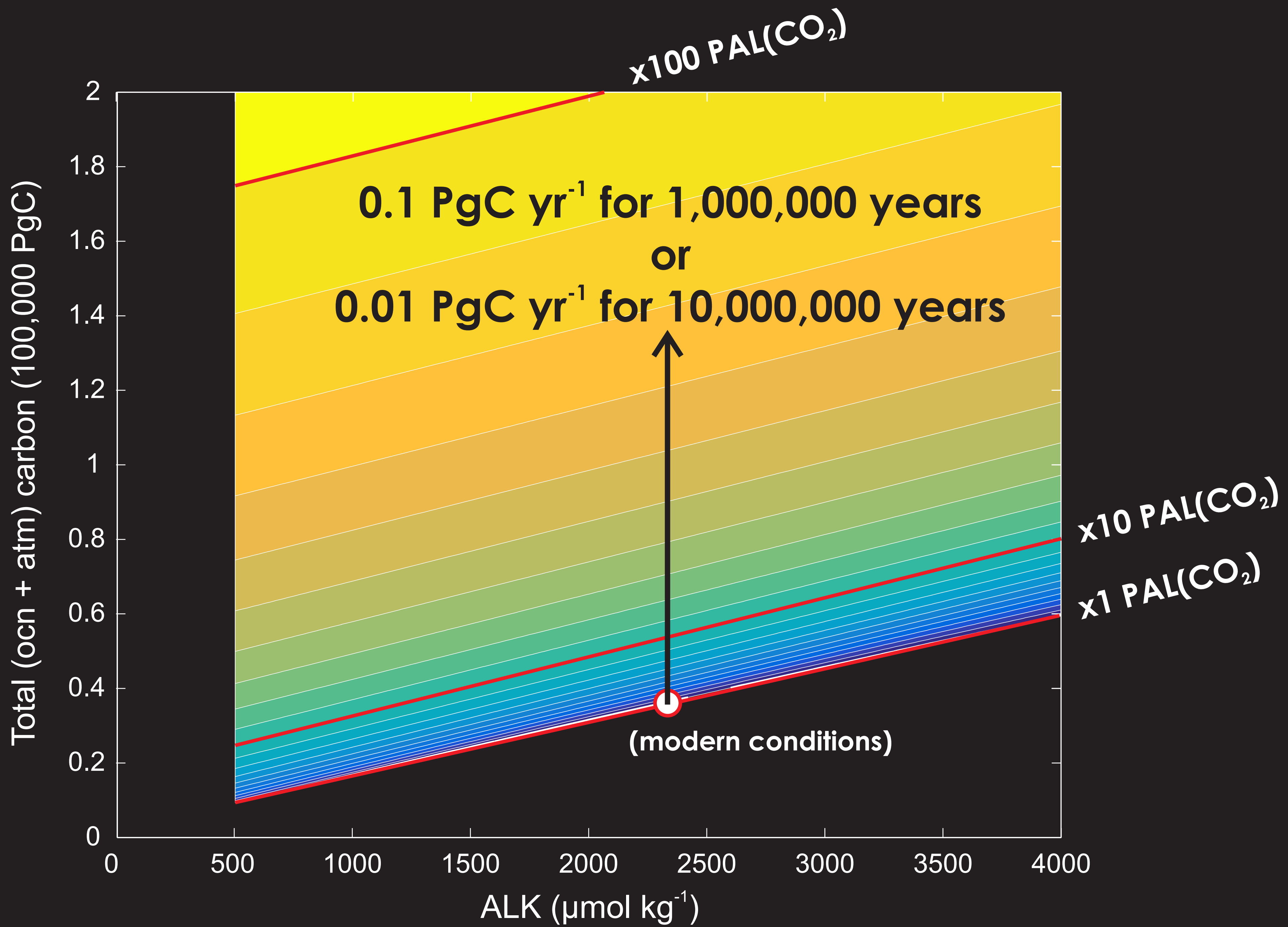


Long-term regulation & evolution of global climate



Terrestrial weathering can be (approximately equally) divided into carbonate ($CaCO_3$) and calcium-silicate ('$CaSiO_3$') weathering:

(1) $2CO_{2(aq)} + H_2O + CaSiO_3 \rightarrow Ca^{2+} + 2HCO_3^- + SiO_2$

(2) $CO_{2(aq)} + H_2O + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$

Ultimately, the (alkalinity: Ca^{2+}) weathering products must be removed through carbonate precipitation and burial in marine sediments:

(3) $Ca^{2+} + 2HCO_3^- \rightarrow CO_{2(aq)} + H_2O + CaCO_3$

It can be seen that in (2) + (3), that the CO_2 removed (from the atmosphere) during weathering, is returned upon carbonate precipitation (and burial). In (1) + (3) (silicate weathering) CO_2 is permanently removed to the geological reservoir. This CO_2 must be balanced by mantle (/volcanic) out-gassing on the very long term.

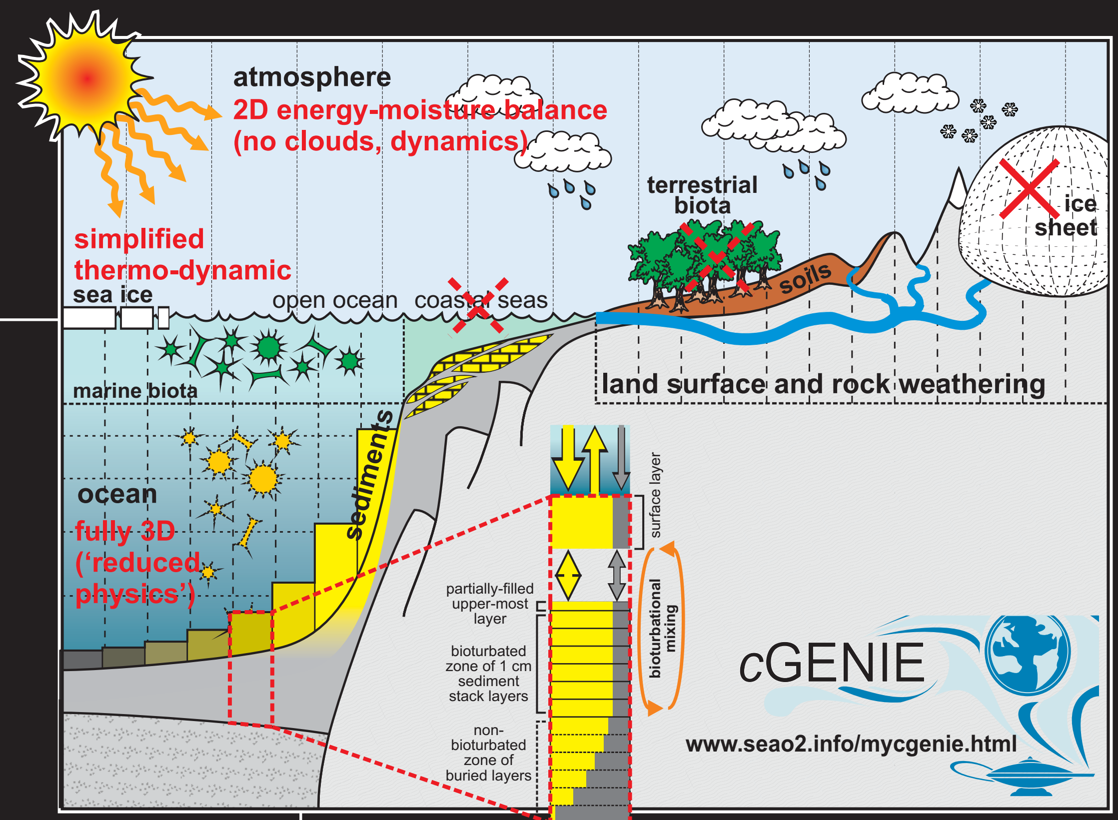
Furthermore, the rate of silicate weathering should scale with climate.

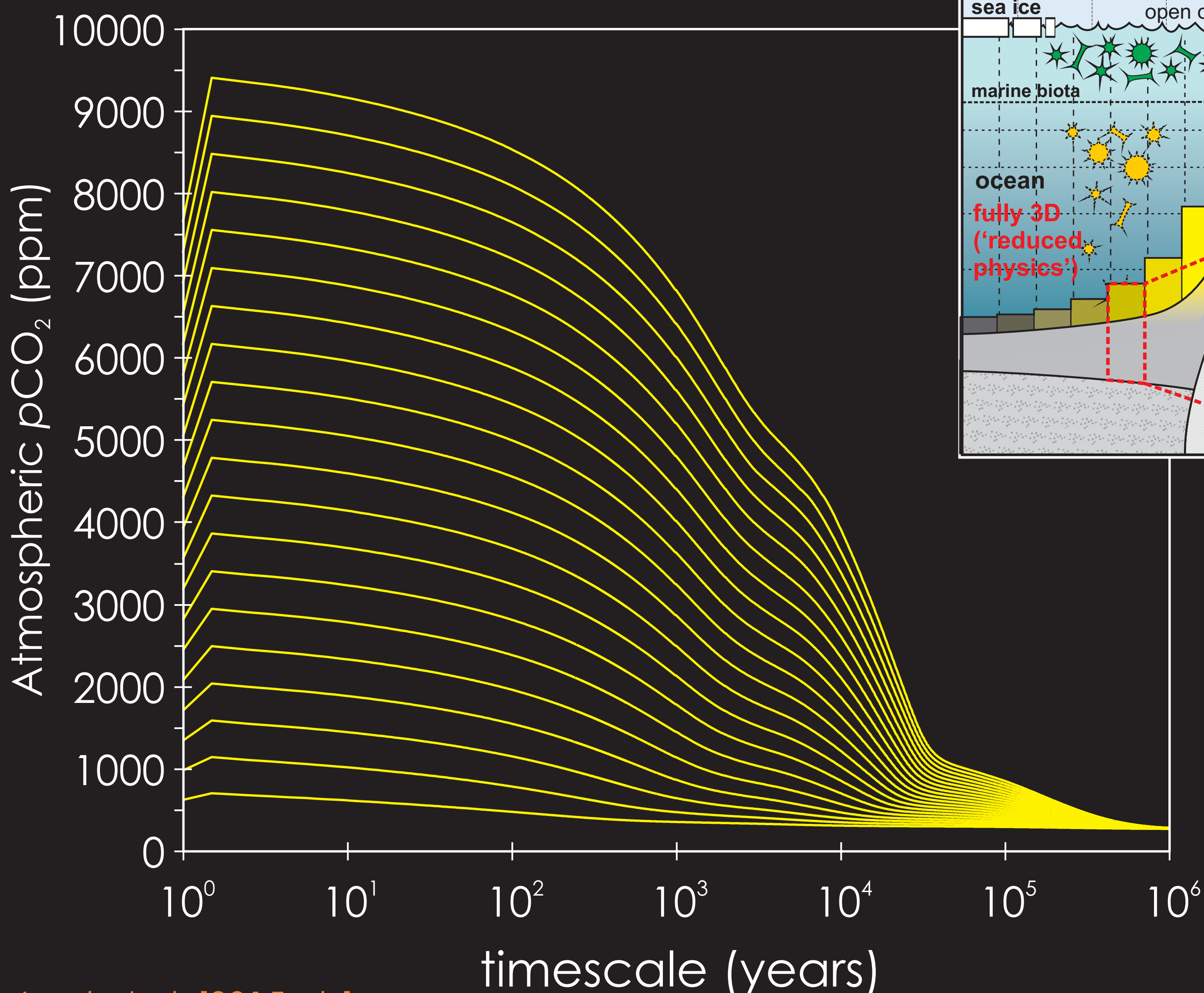
Hence the **silicate weathering feedback** is formed:

higher pCO_2 ⇒ higher temperatures
⇒ higher rates of weathering
⇒ lower pCO_2

The 'long tail' of $CO_{2(excess)}$

(1) Series of 1 Myr Earth system model experiments. CO_2 emissions from 1,000 to 20,000 PgC (GtC). Release interval: 1 yr.





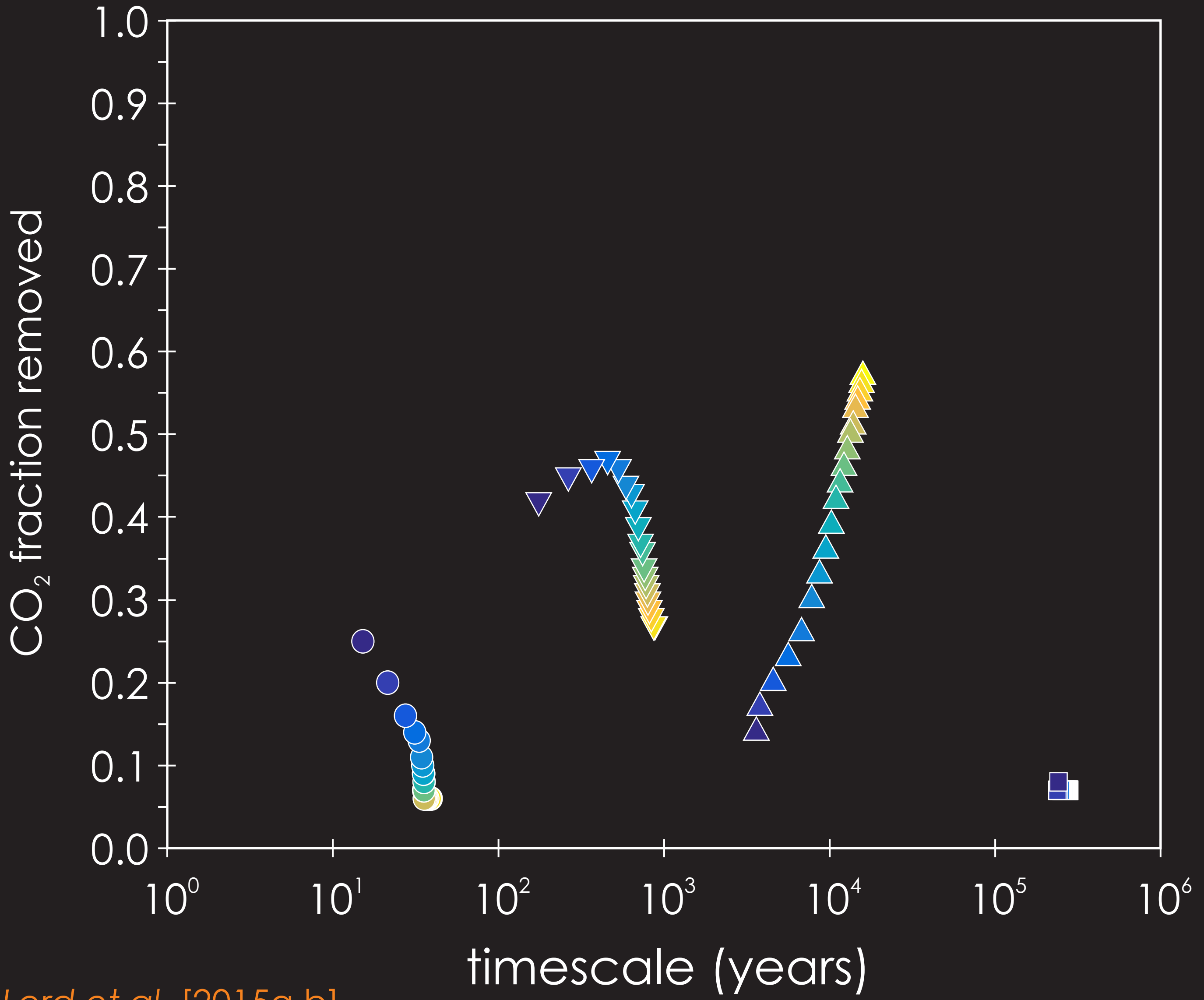
(2) Fit each CO_2 decay curve with a series (4 optimal) of exponentials. Extract the fraction of CO_2 and time-scale associated with each.

(The resulting empirical model can be used in place of a mechanistic model for projecting the long-term fate of carbon release.)

Lord et al. [2015a,b]

The 'long tail' of $CO_{2(excess)}$

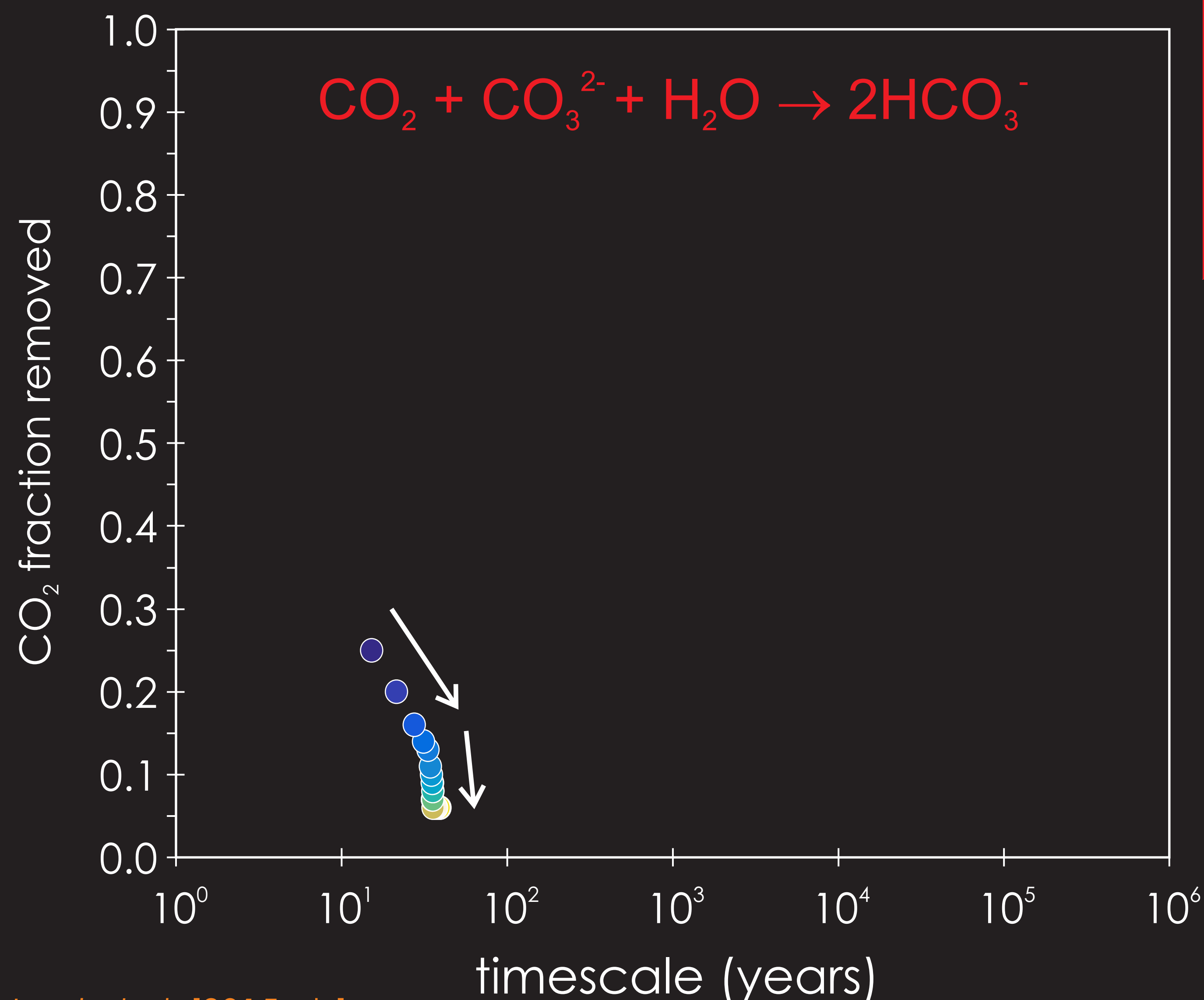
Response of fraction of CO_2 removed vs. the characteristic time-scale, as a function of total emissions, ranging from 1,000 PgC (dark blue) to 20,000 PgC (yellow).

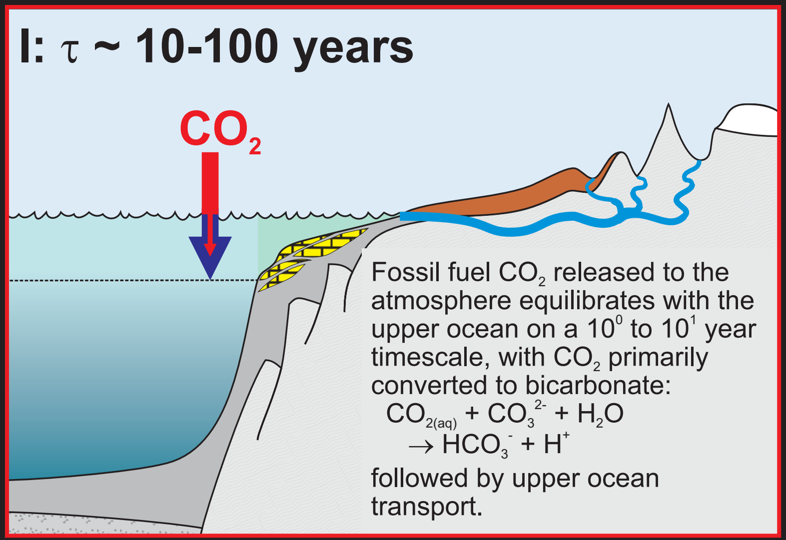


Lord et al. [2015a,b]

The ‘long tail’ of $CO_{2(excess)}$

Depletion of mixed layer carbonate buffer; ocean stratification and reduced surface mixing. Warming and reduced CO_2 solubility.

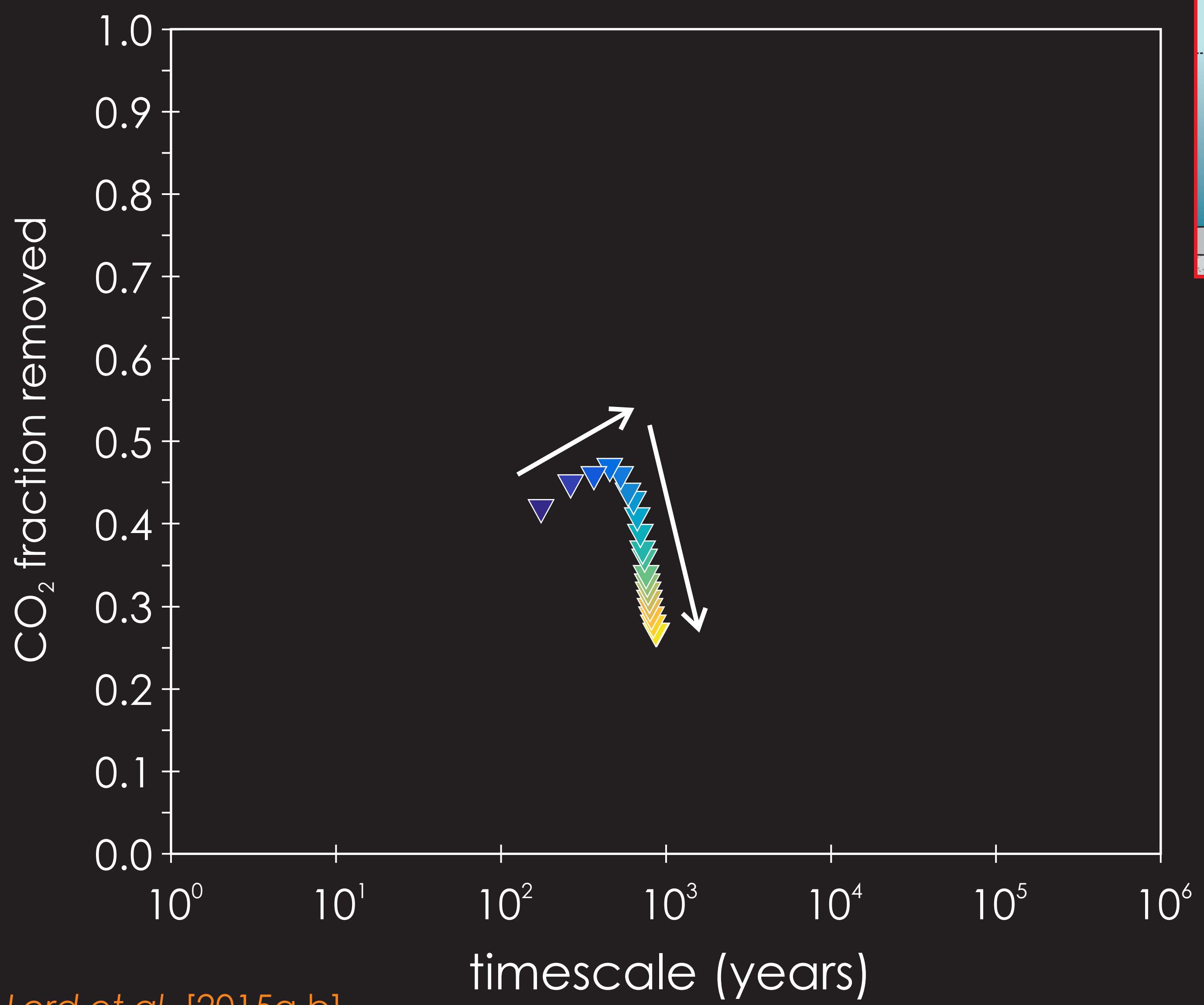


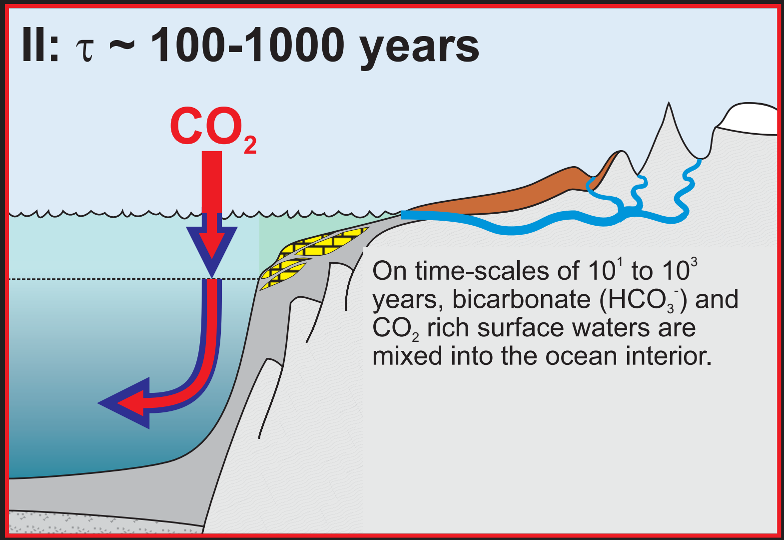


Lord et al. [2015a,b]

The 'long tail' of $CO_{2(excess)}$

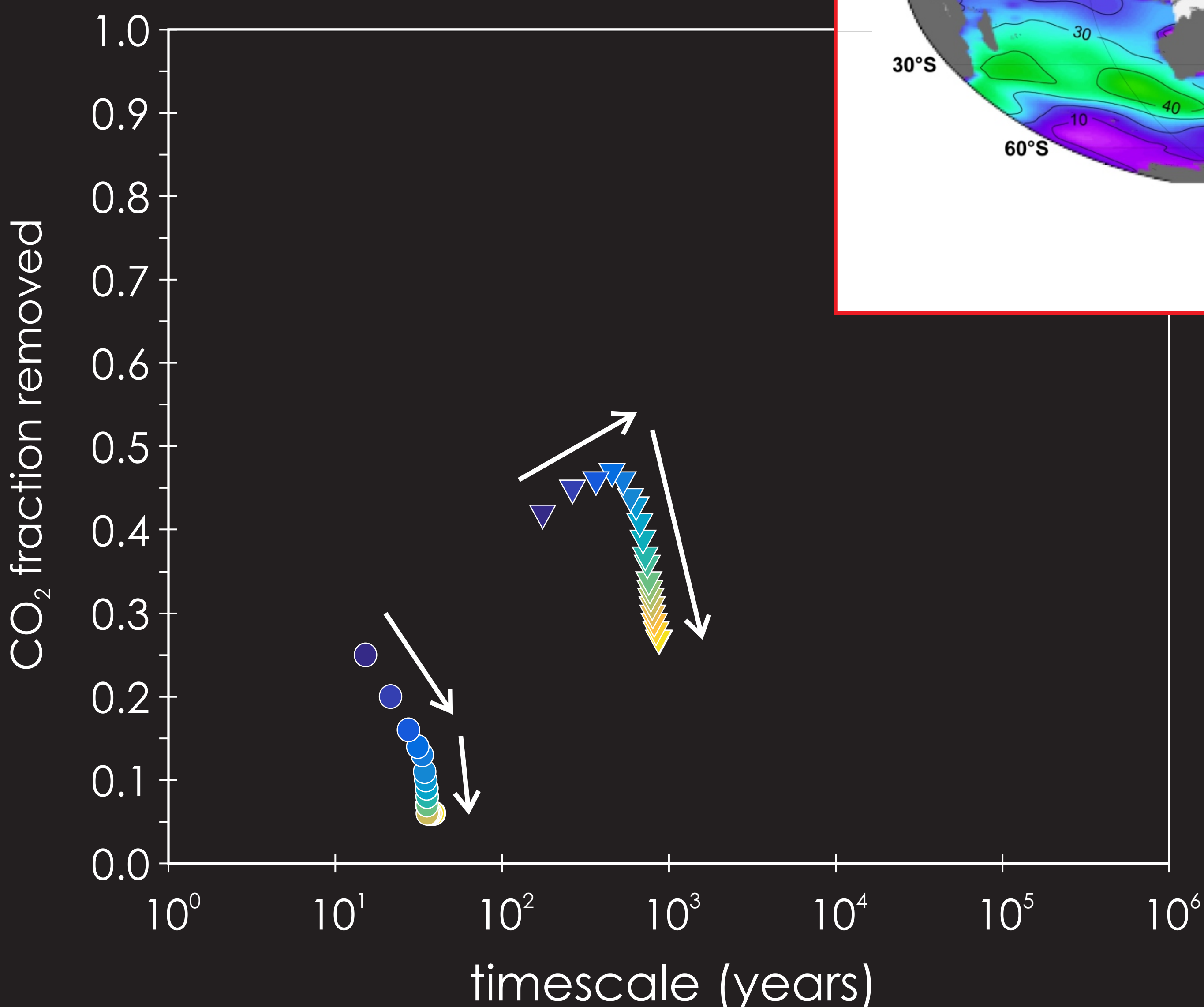
Ocean stratification and collapse of the AMOC
(in this particular model).
Threshold reached @ ~4000 PgC?

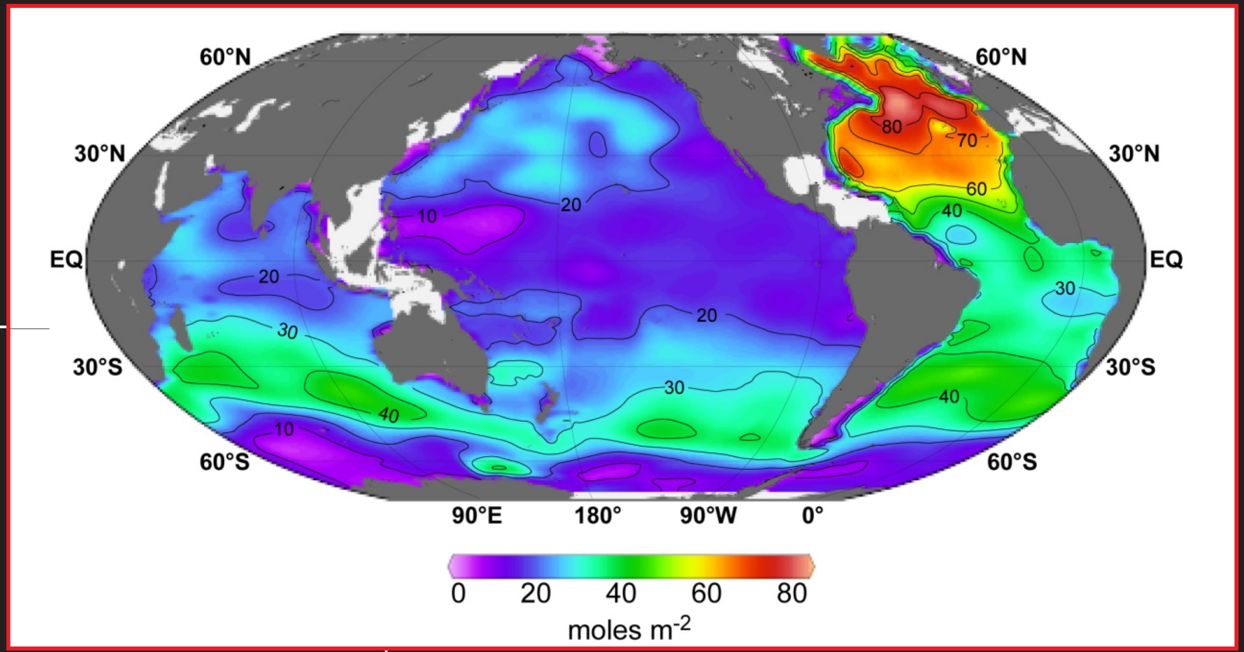




Lord et al. [2015a,b]

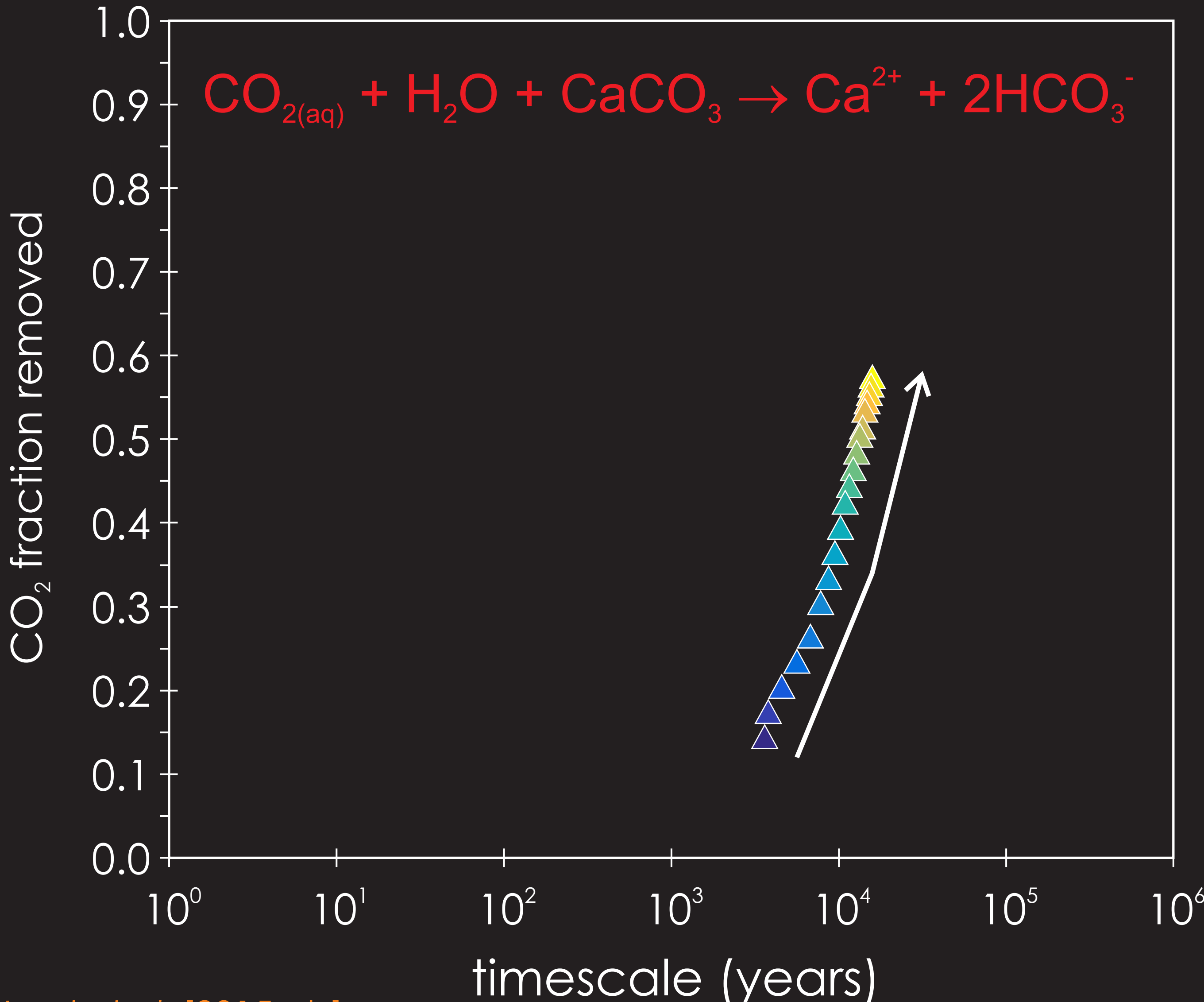
The 'long tail' of $CO_{2(excess)}$

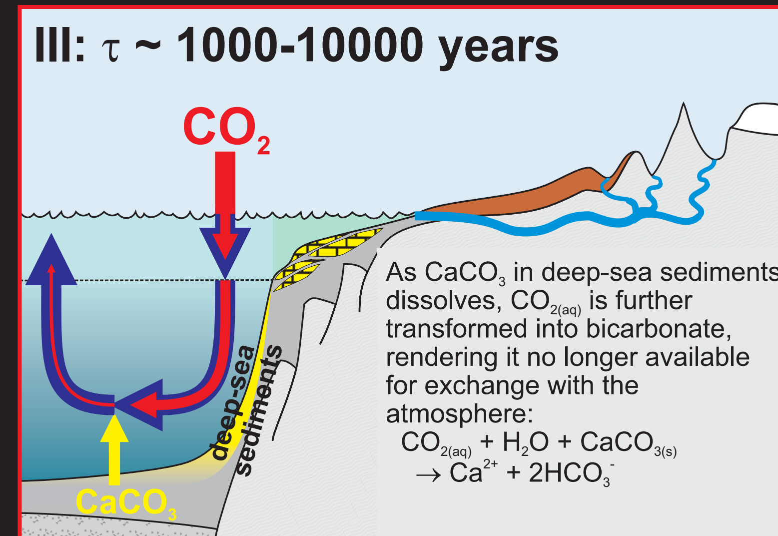


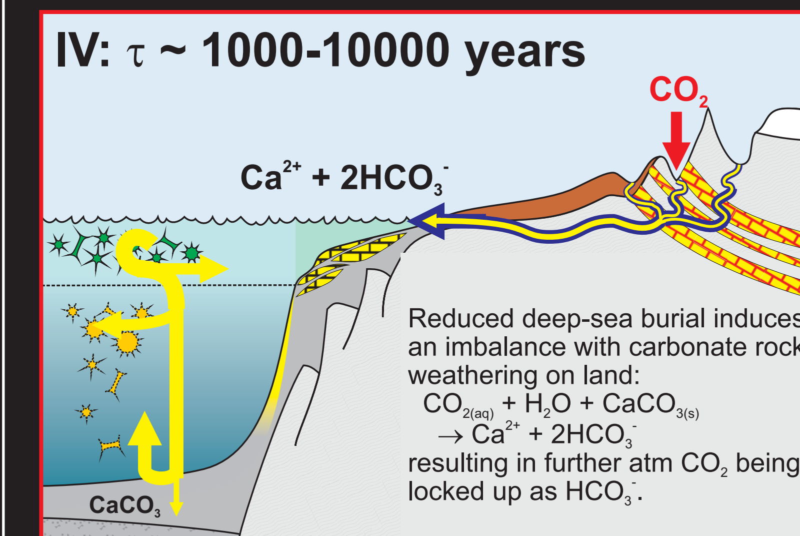


The 'long tail' of $CO_{2(excess)}$

Geologic CO_2 removal via carbonate rocks and marine sediments – occurring on an increasing protracted time-scale.







Lord et al. [2015a,b]

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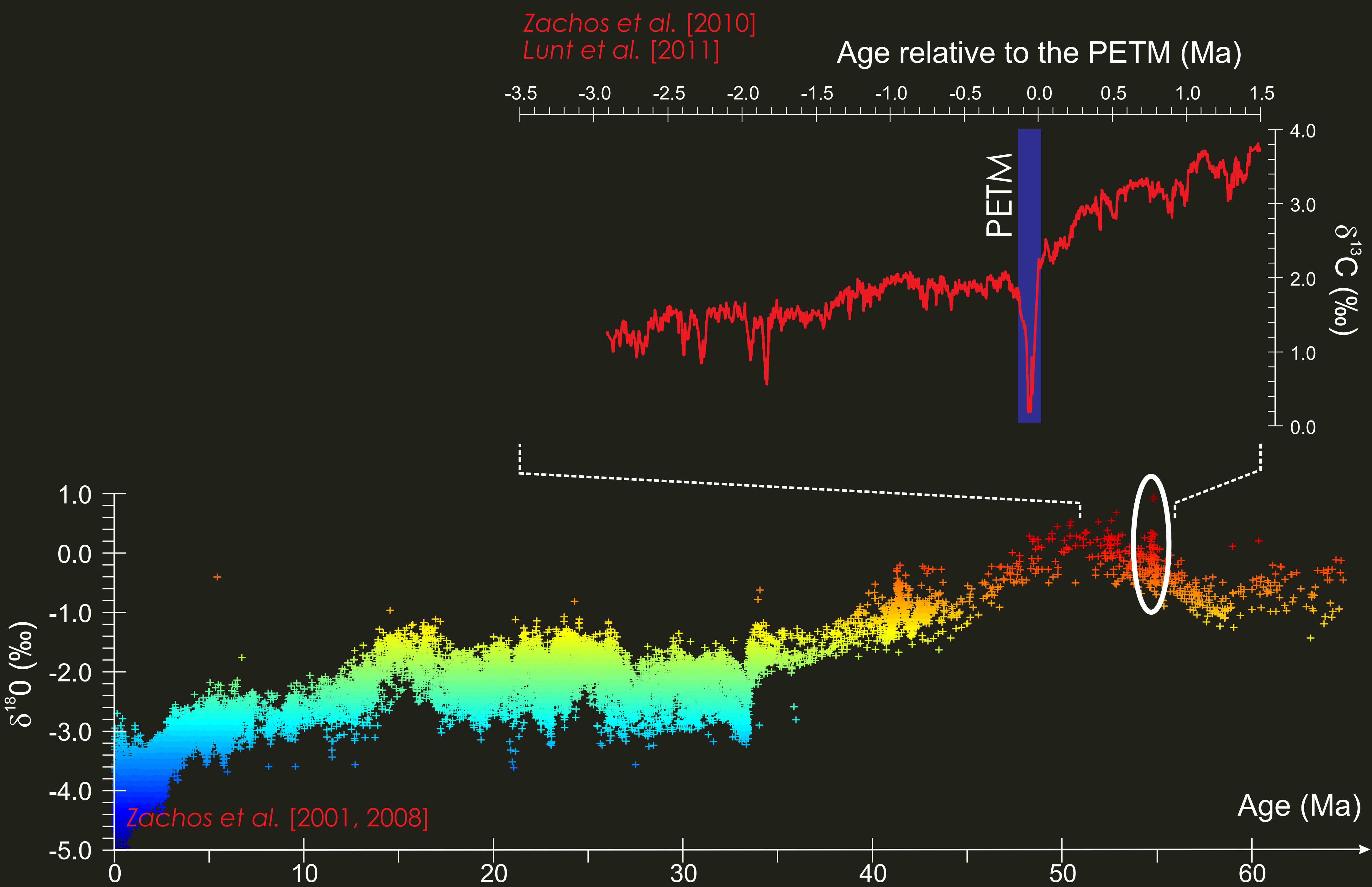

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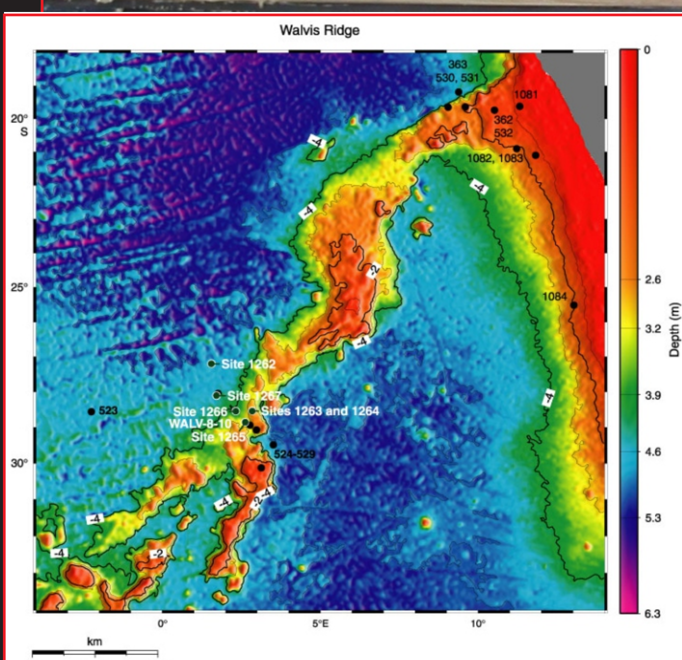
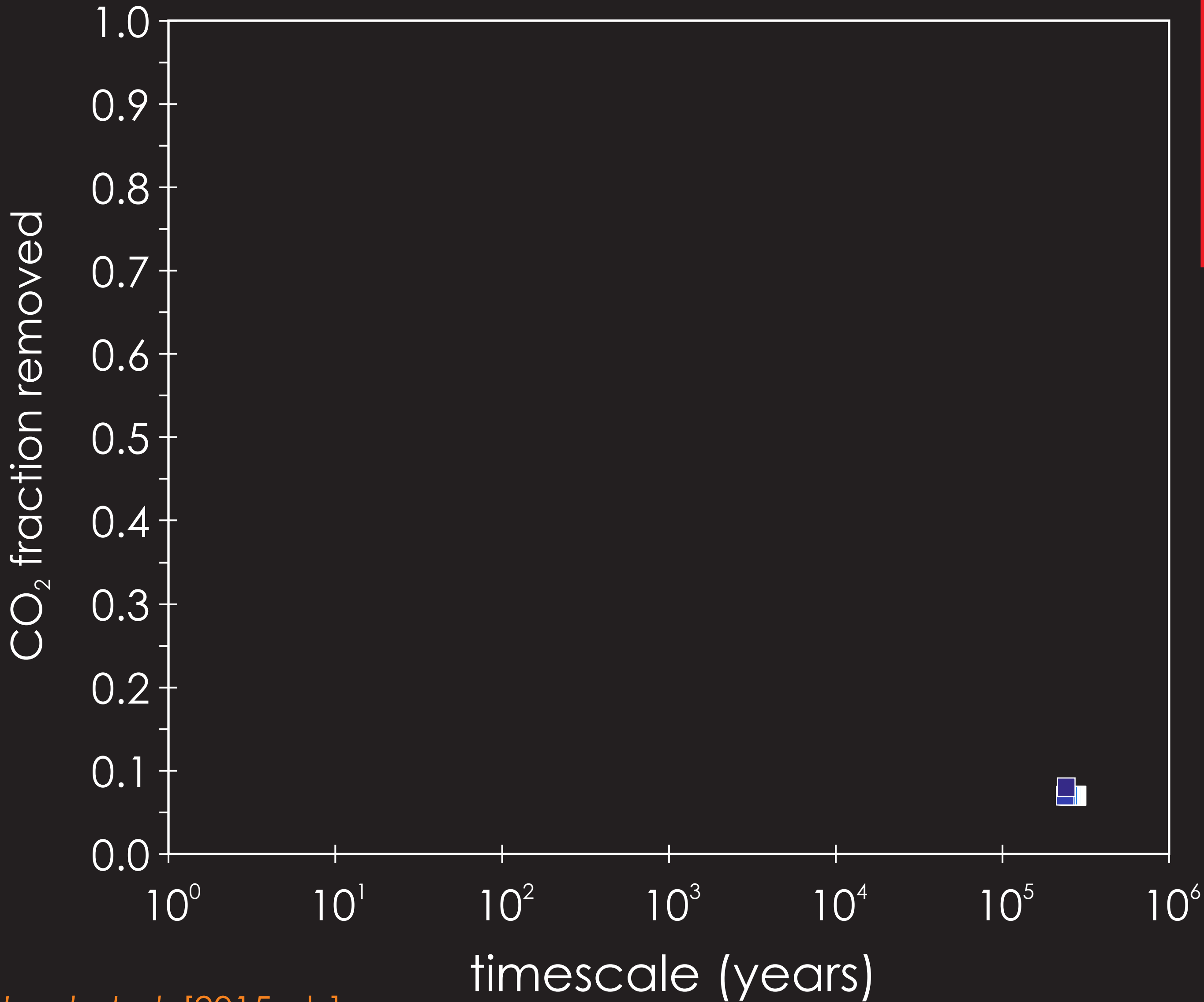
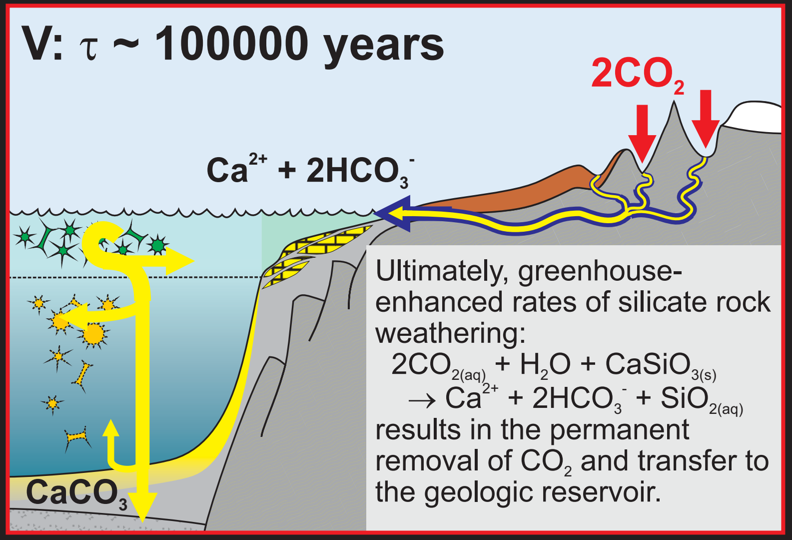


Sediments spanning the Palaeocene-Eocene boundary from ODP Leg 208 (Walvis Ridge)
Picture courtesy of Dani Schmidt (University of Bristol)

The 'long tail' of $CO_{2(excess)}$

Silicate weathering (no time-scale response!).





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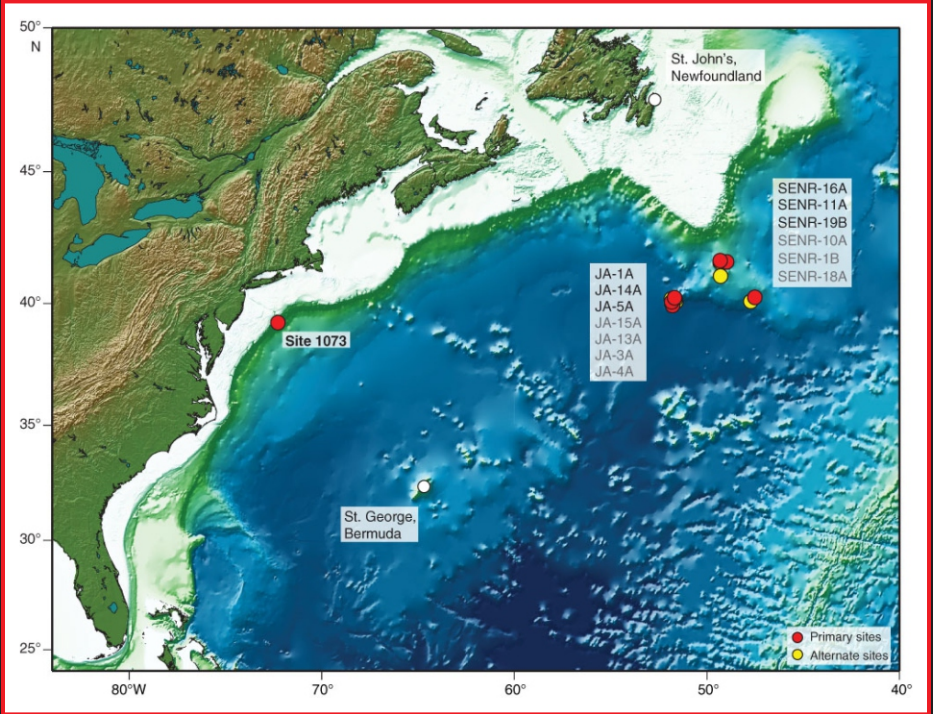

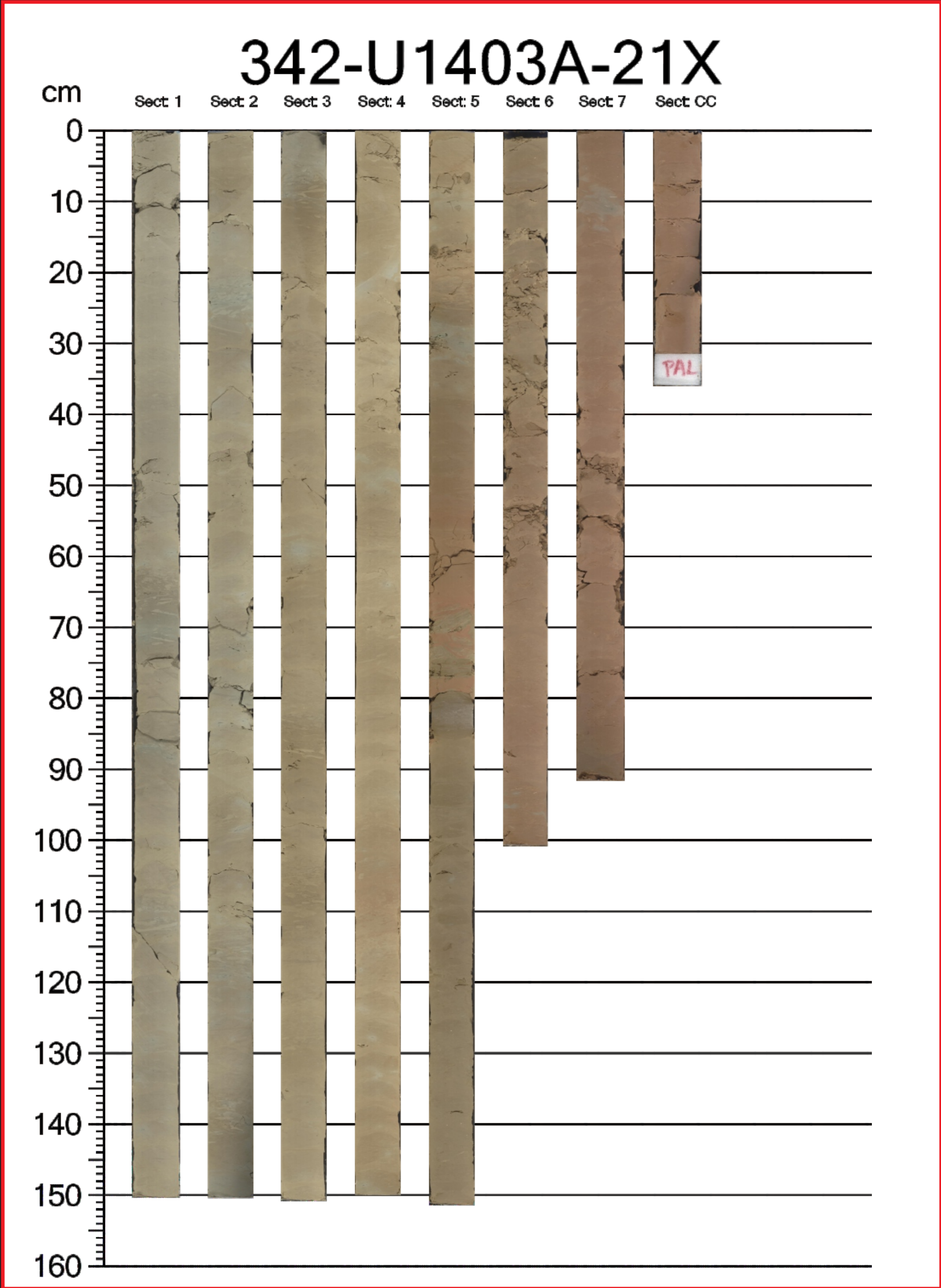

Controls on weathering and the role of plants (?)

Controls on weathering *and the role of plants* (?)

$$\text{weathering} \propto f\left(\begin{matrix}\text{soil properties}\\ \text{rock mineralogy}\end{matrix}\right) \otimes f\left(\begin{matrix}\text{hydrology}\\ \text{temperature}\\ pCO_2\end{matrix}\right) \otimes f\left(\begin{matrix}\text{plant productivity}\\ \text{plant (roots) type}\end{matrix}\right)$$

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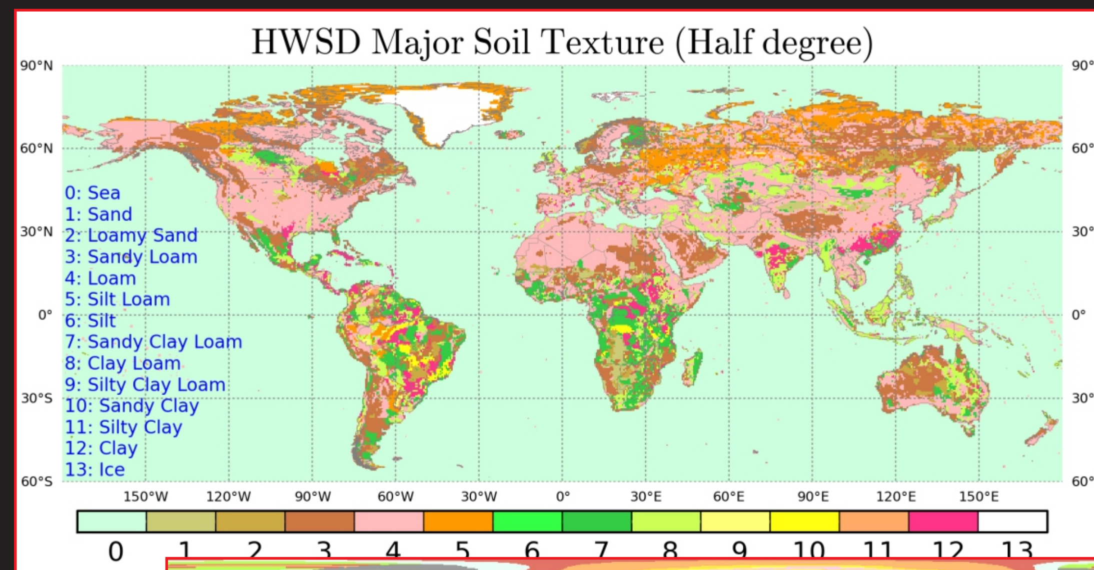

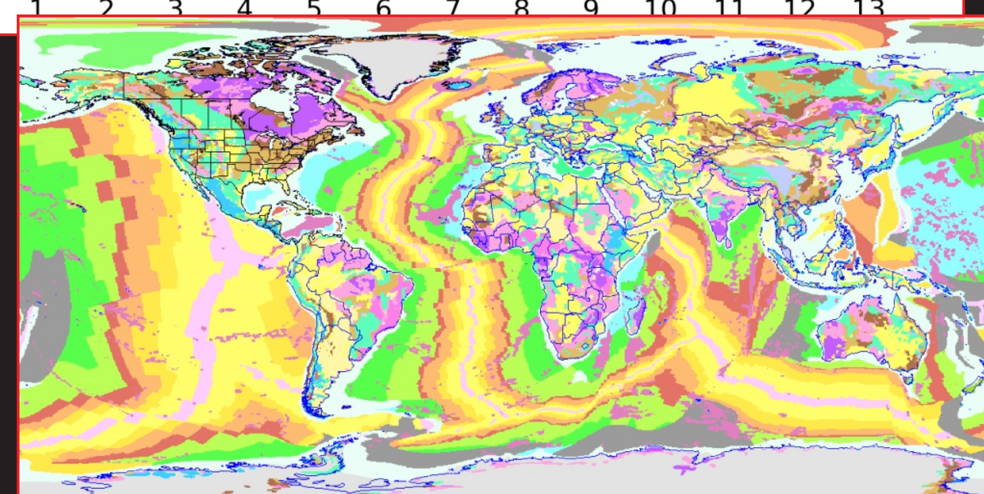

Controls on weathering and the role of plants (?)

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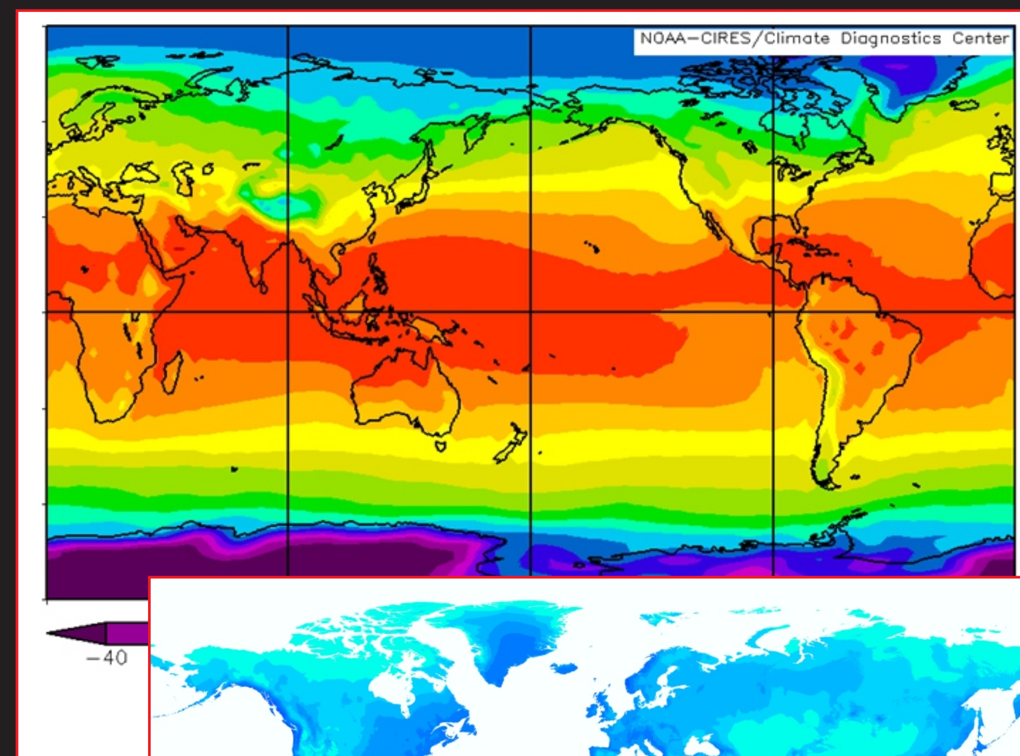

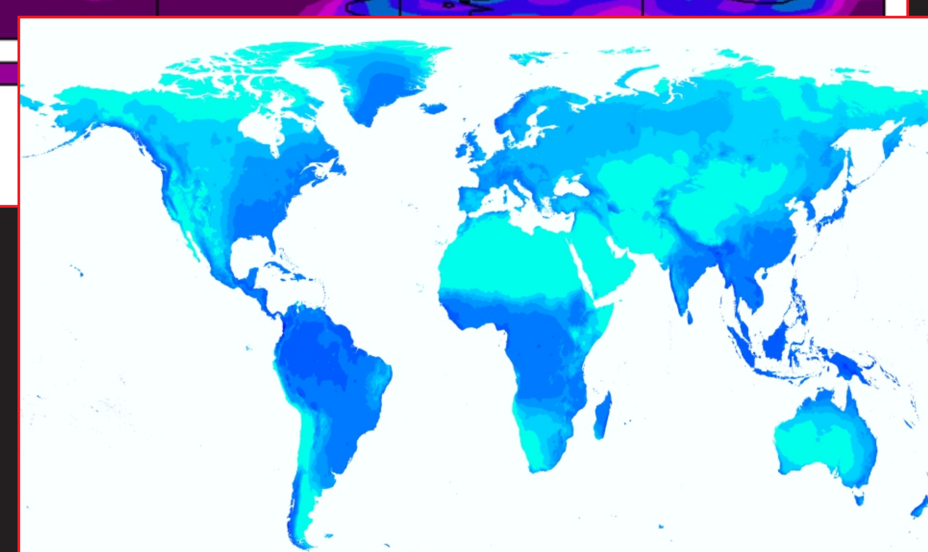

Controls on weathering *and the role of plants* (?)

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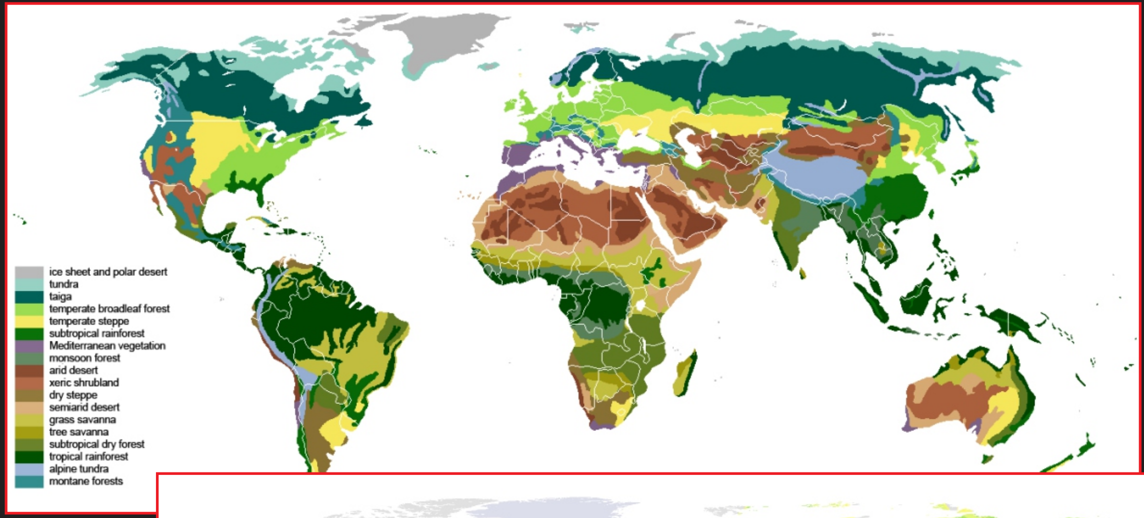

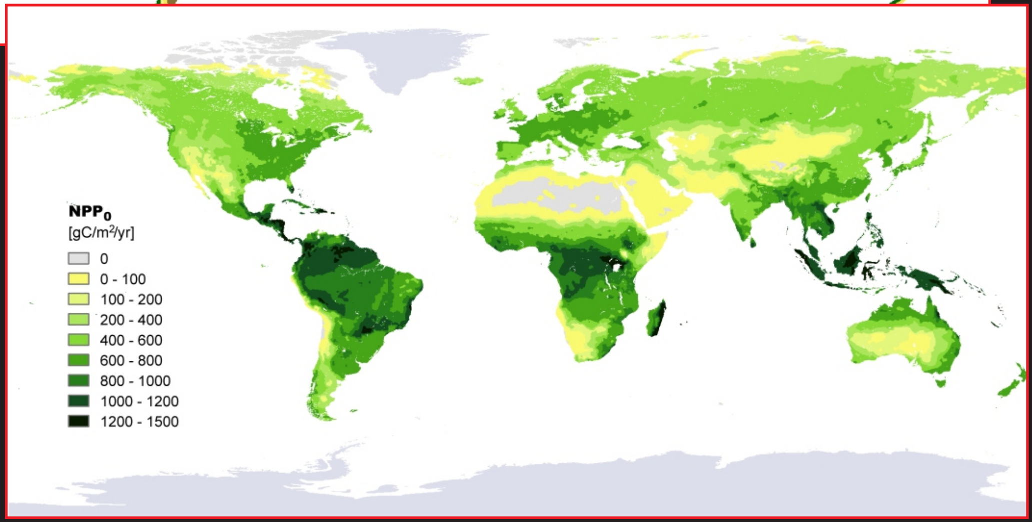

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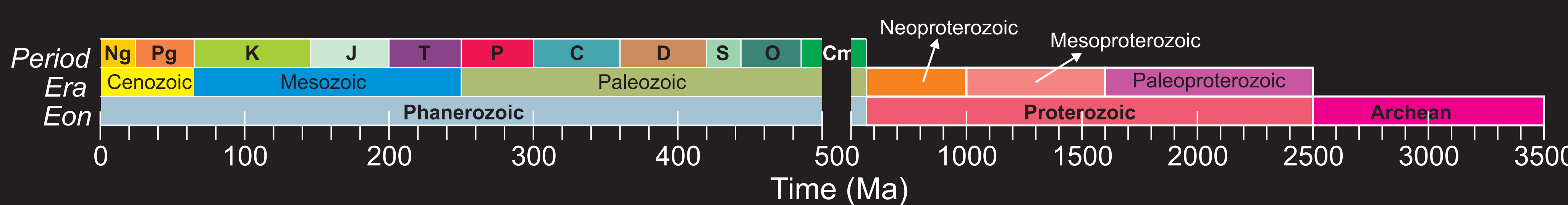
?



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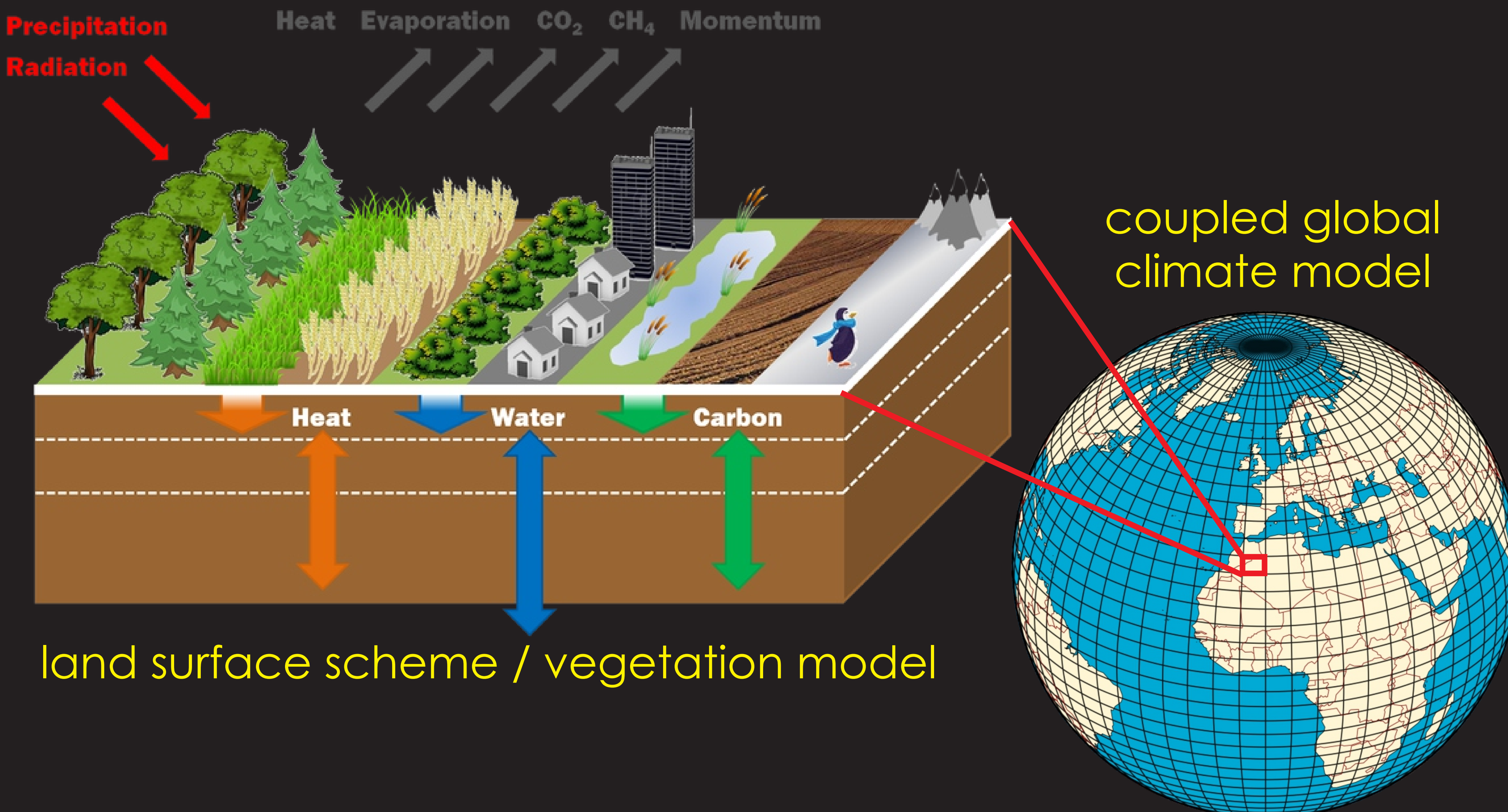

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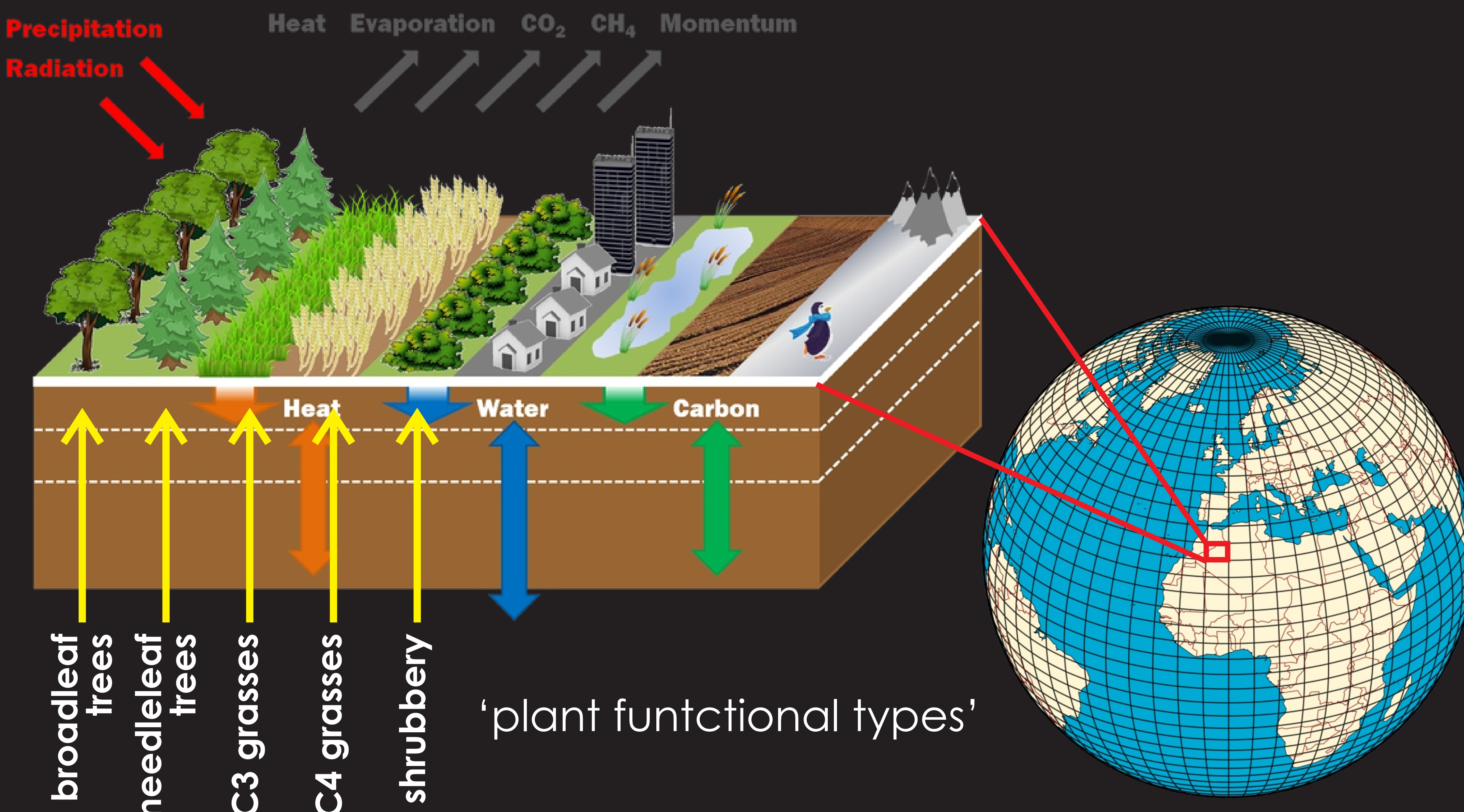

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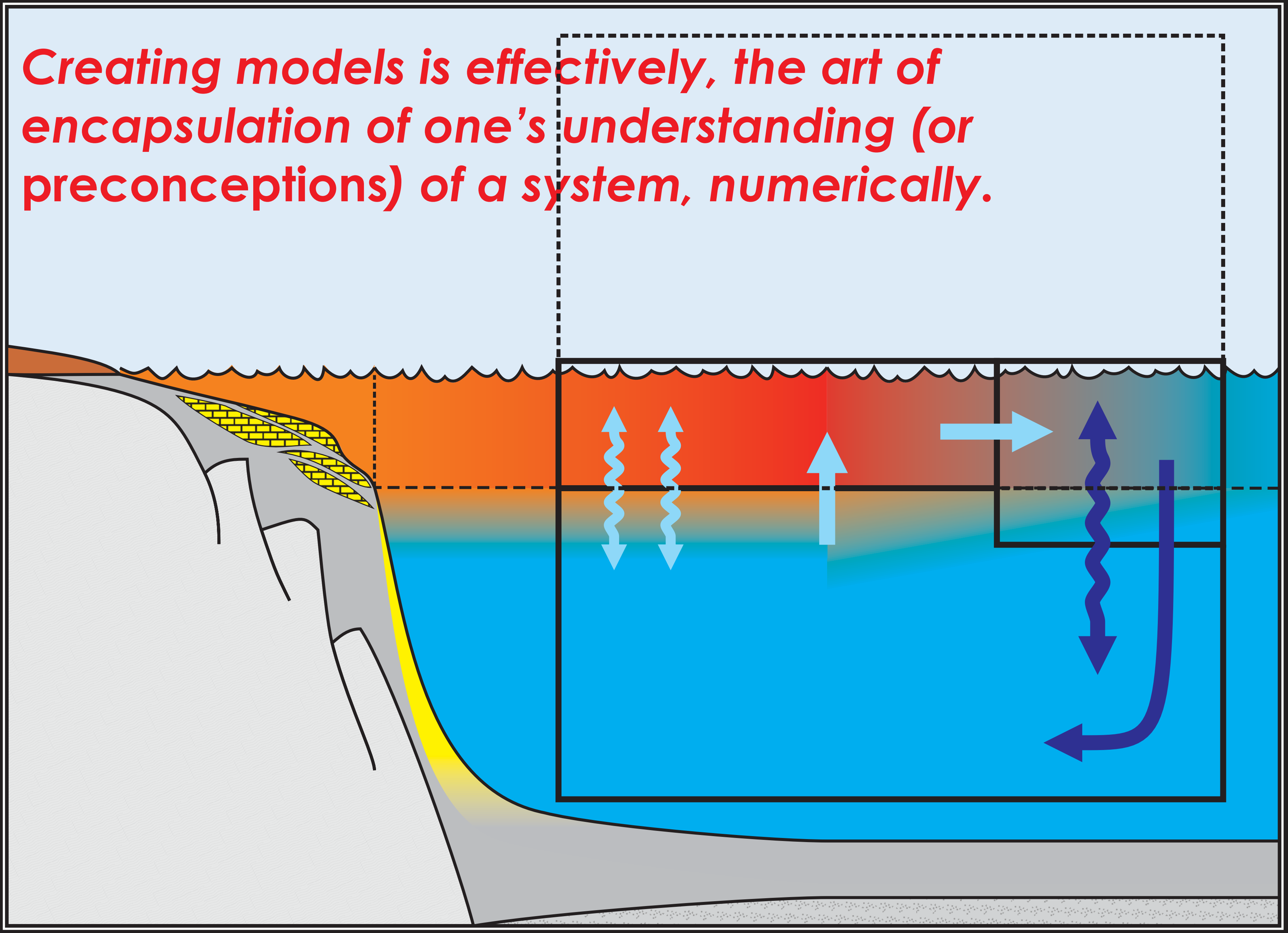

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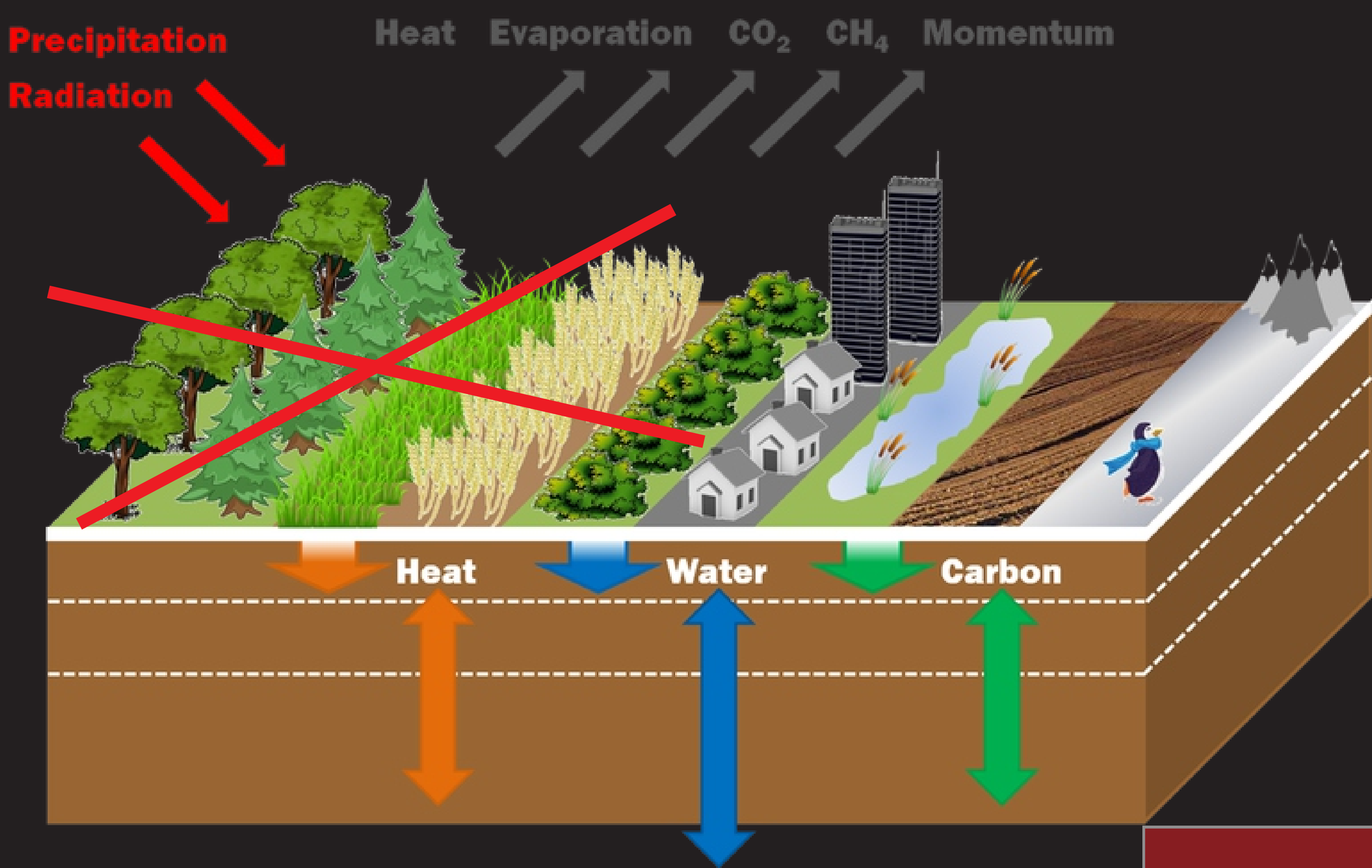

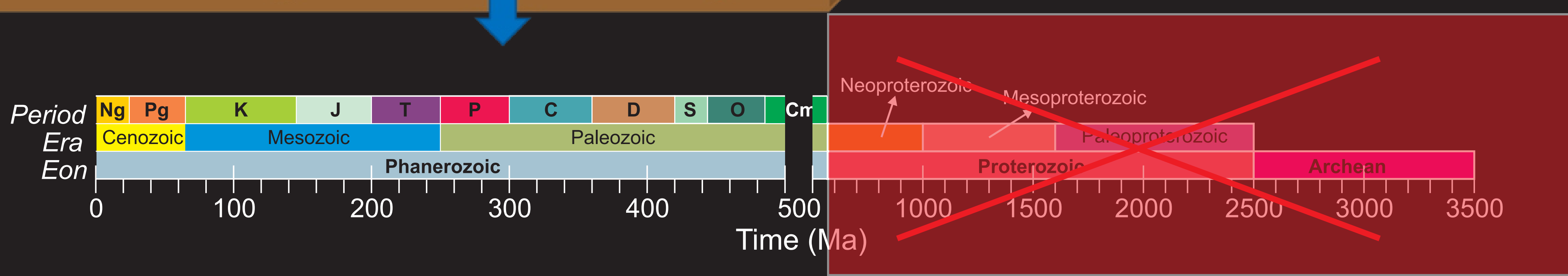

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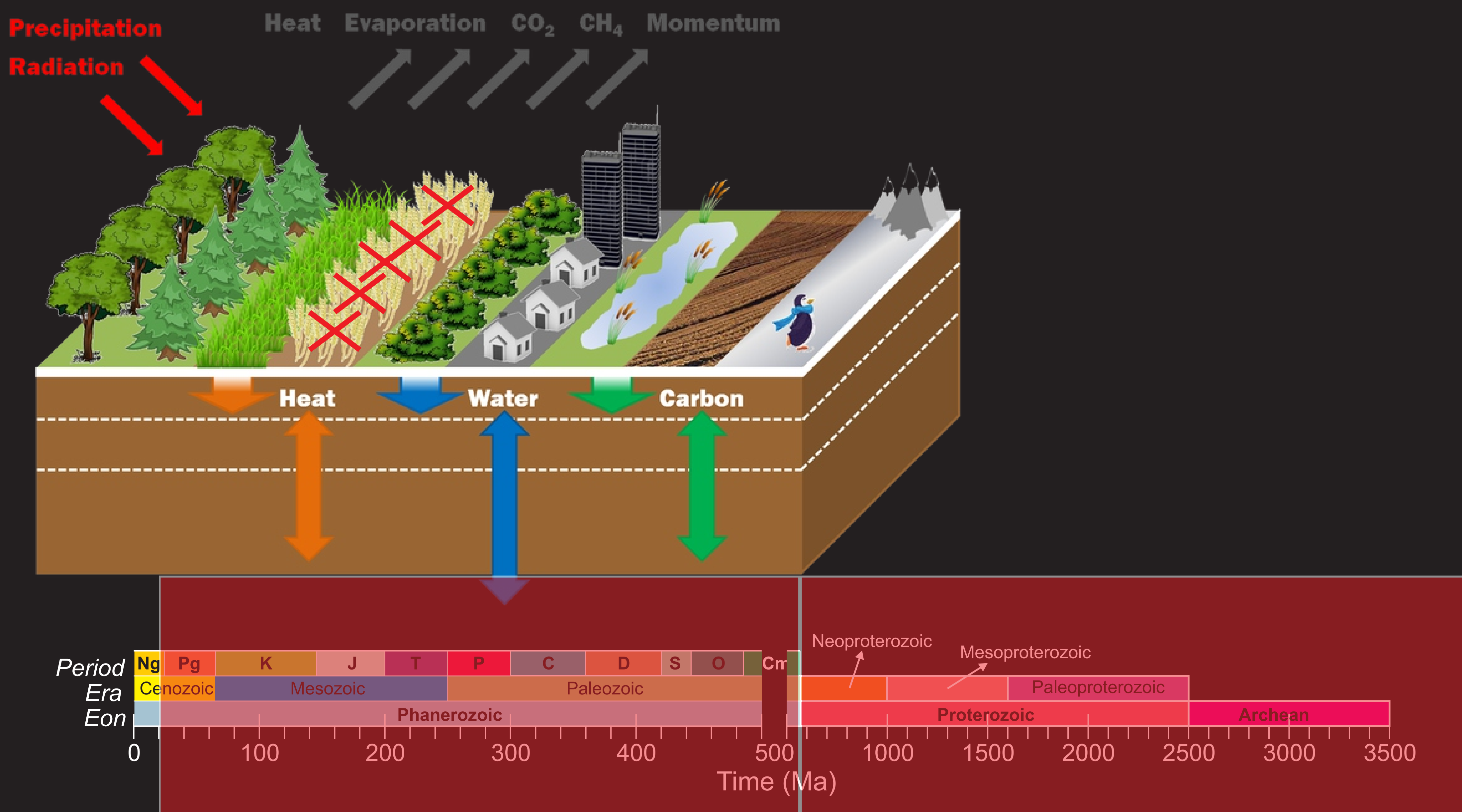

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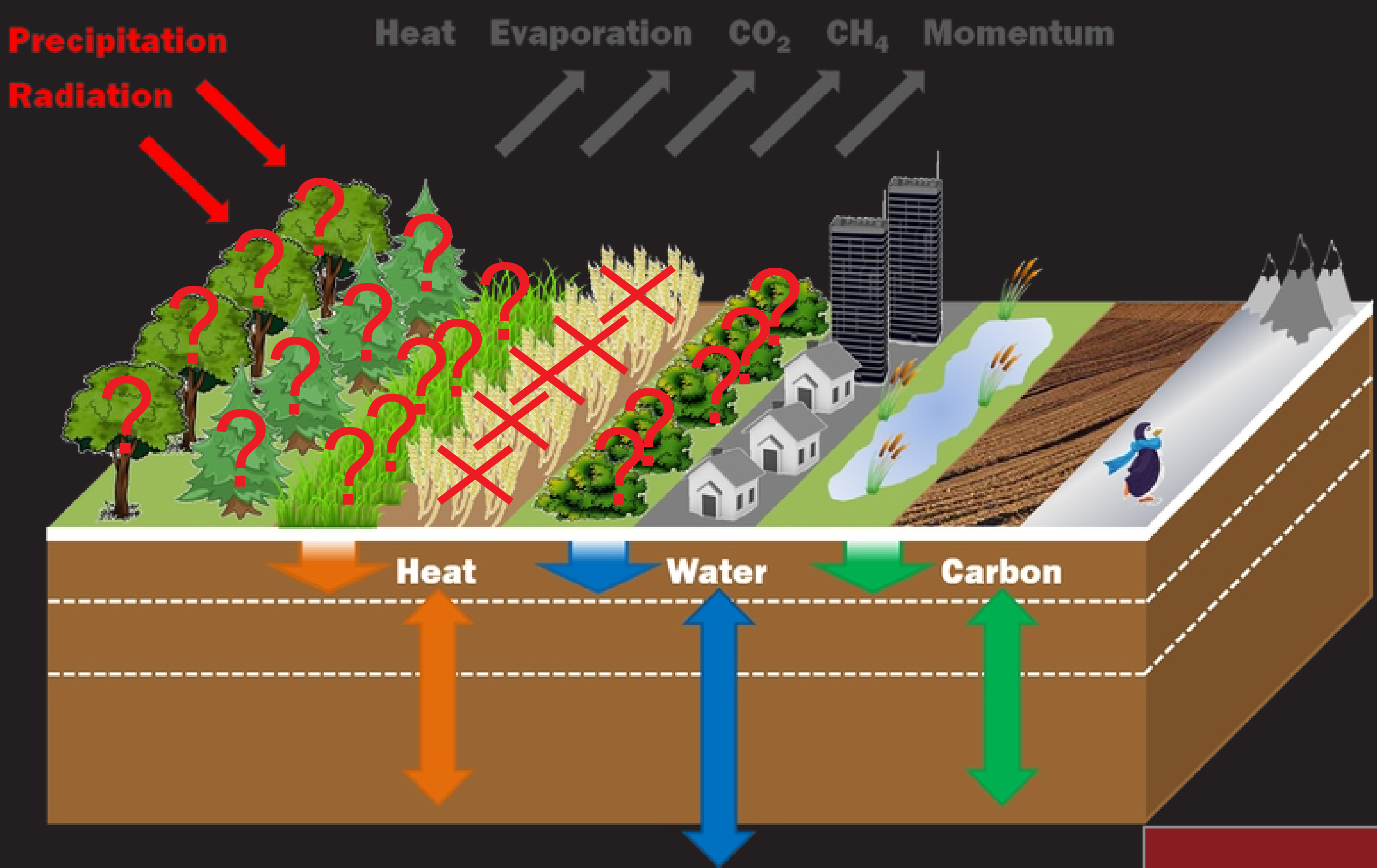

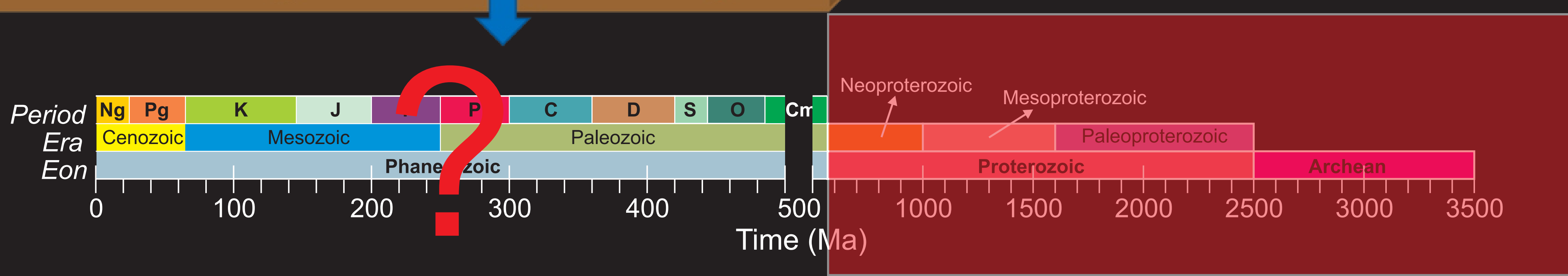

Controls on weathering ***and the role of plants*** (?)

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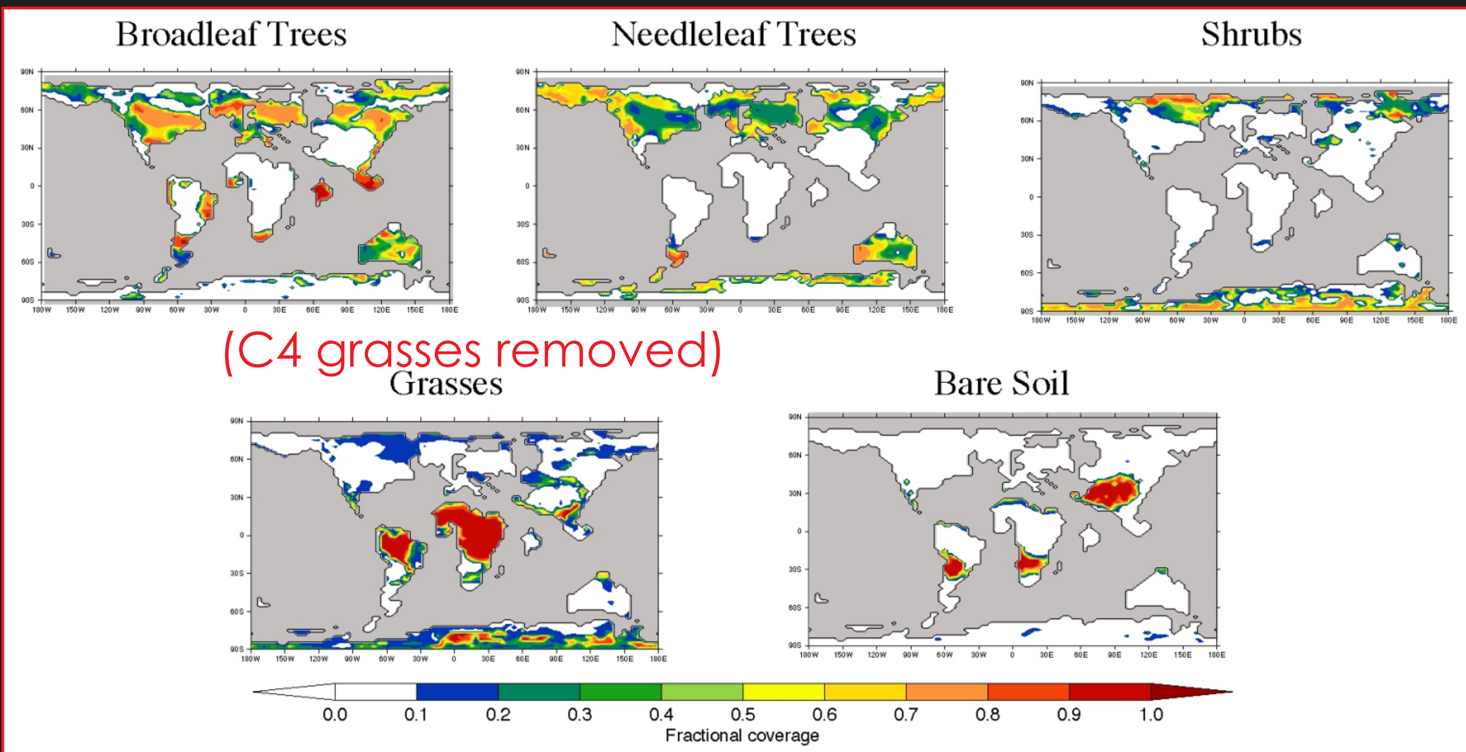
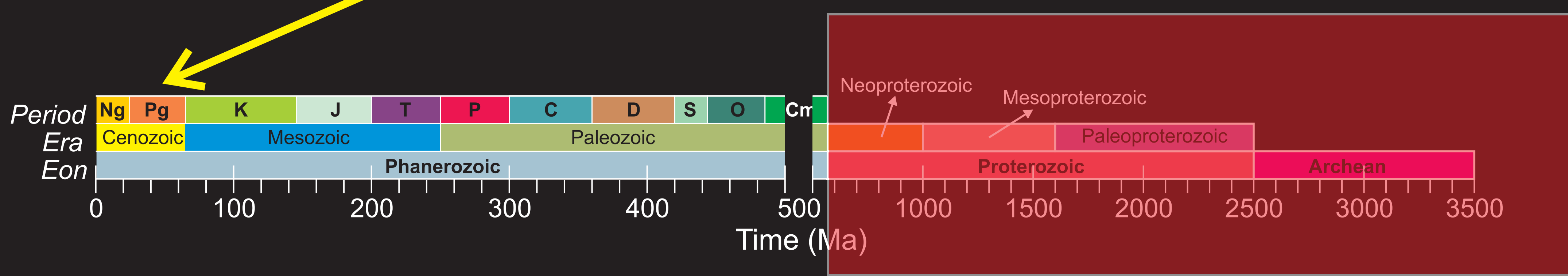


Loptson et al. [2014] (*Clim. Past* **10**, 419–436)



Controls on weathering *and the role of plants* (?)

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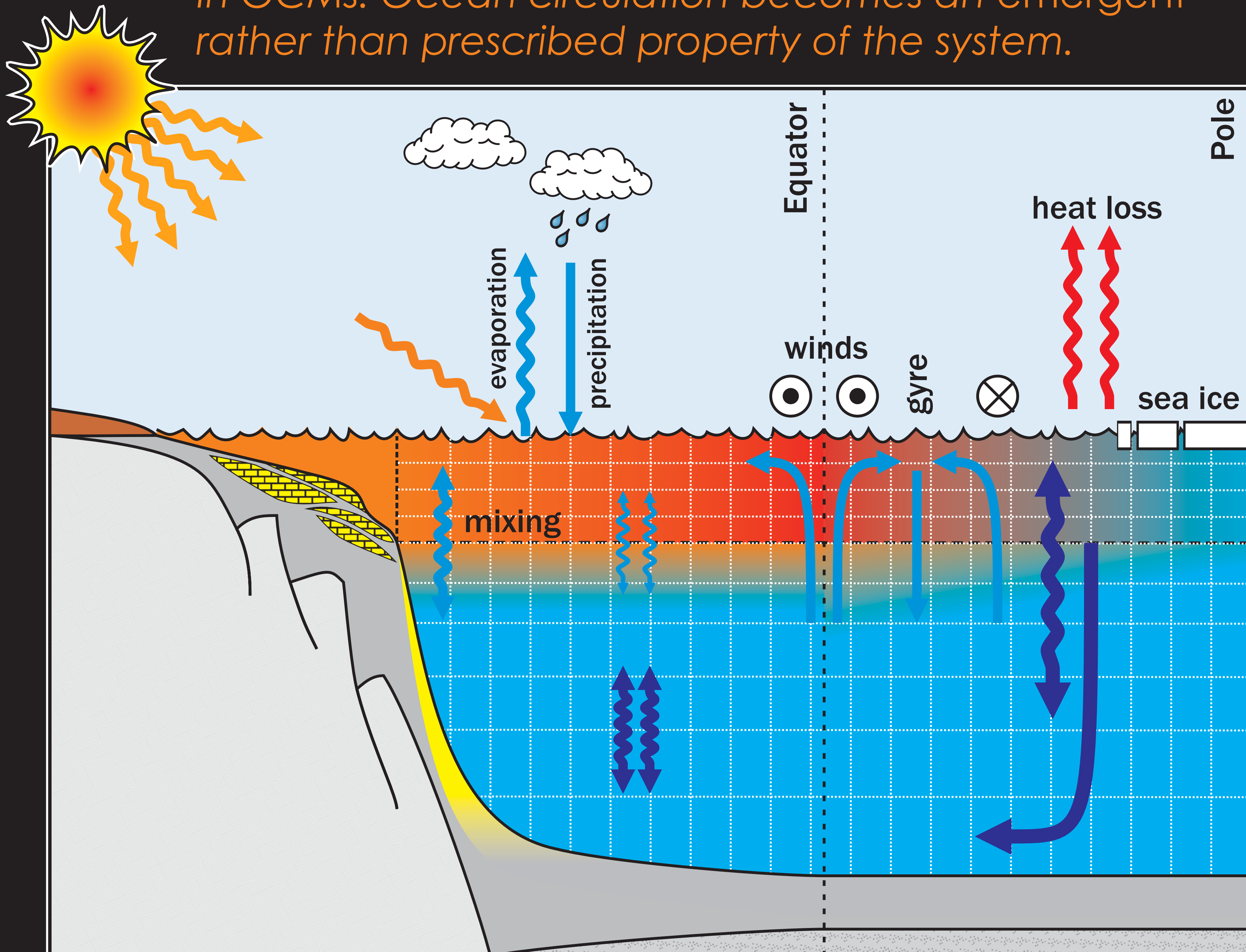
In GCMs: Ocean circulation becomes an emergent rather than prescribed property of the system.



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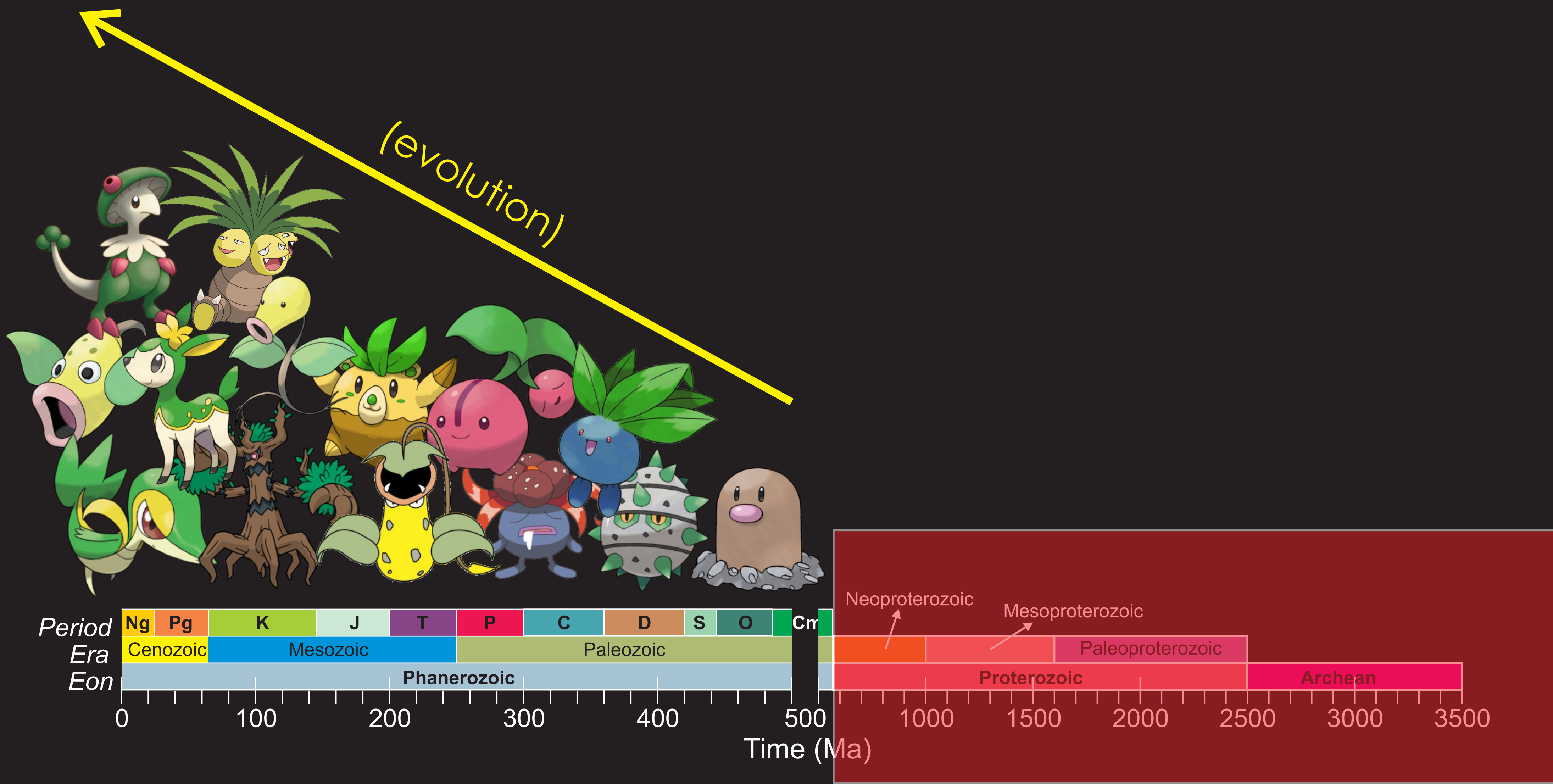
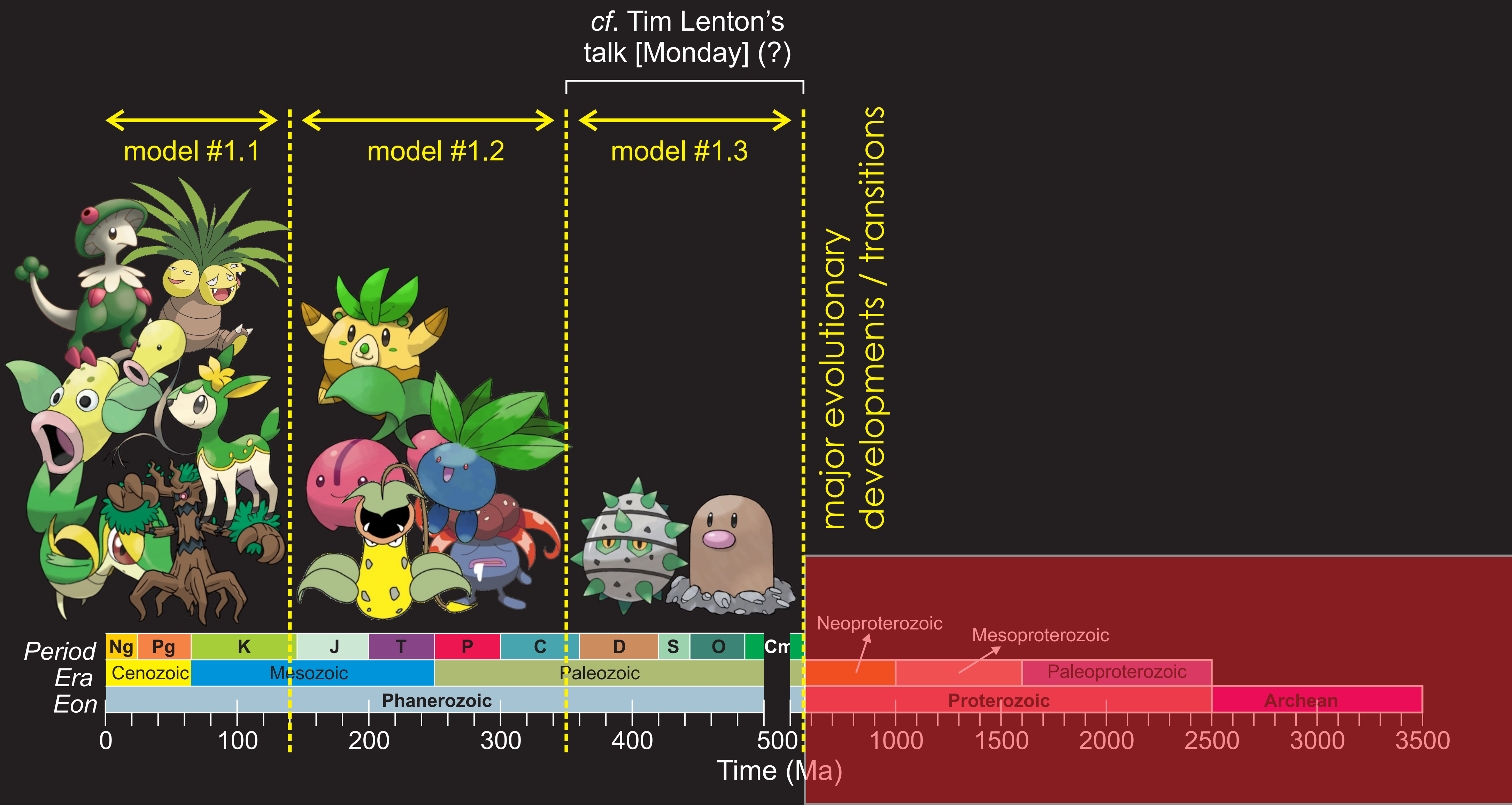
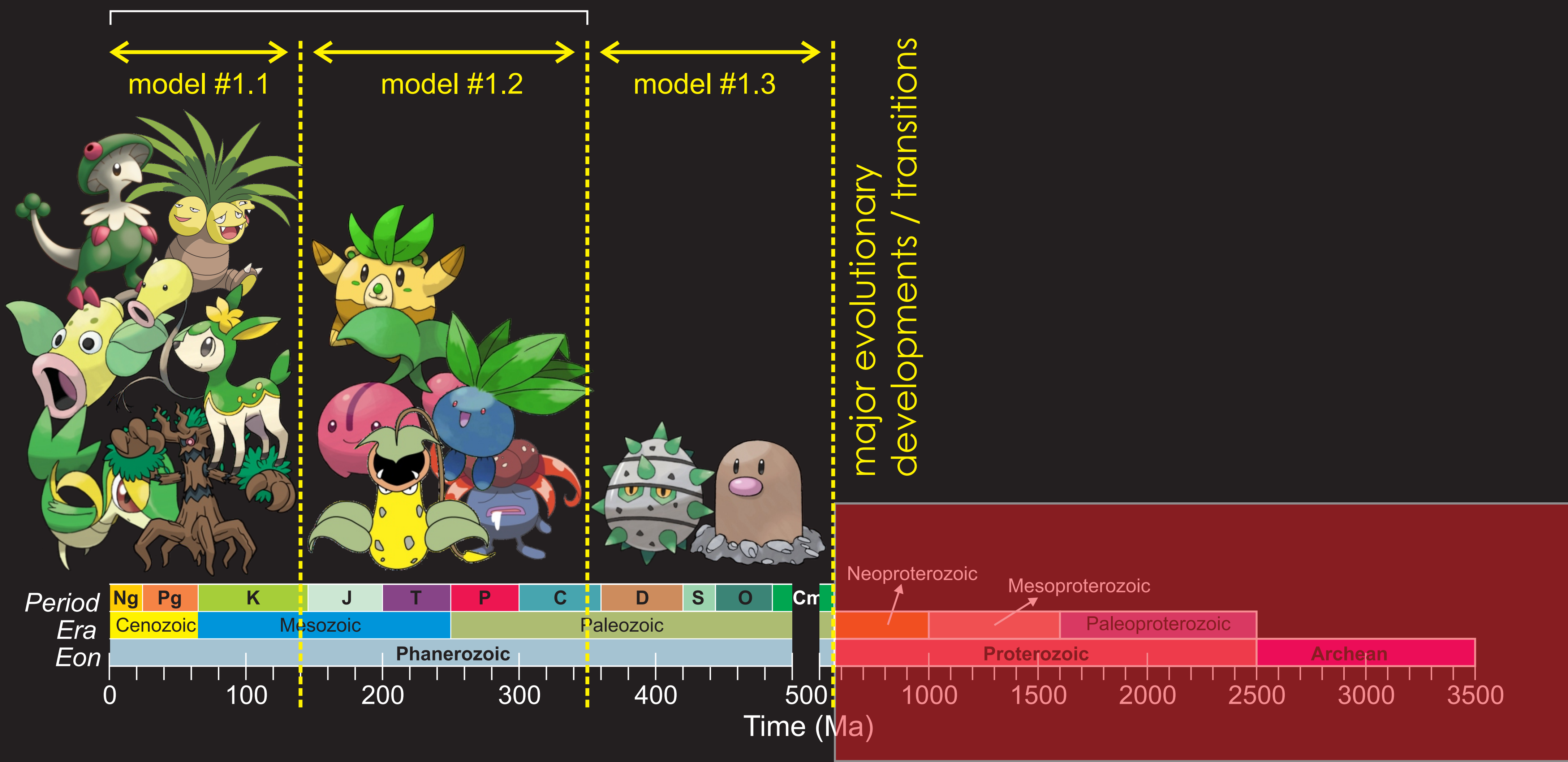


Controls on weathering *and the role of plants* (?)



Controls on weathering *and the role of plants* (?)

Jena Diversity-Dynamic
Global Vegetation Model
(JeDi-DGVM)
[*Pavlick et al.*, 2013, *Biogeosciences*]

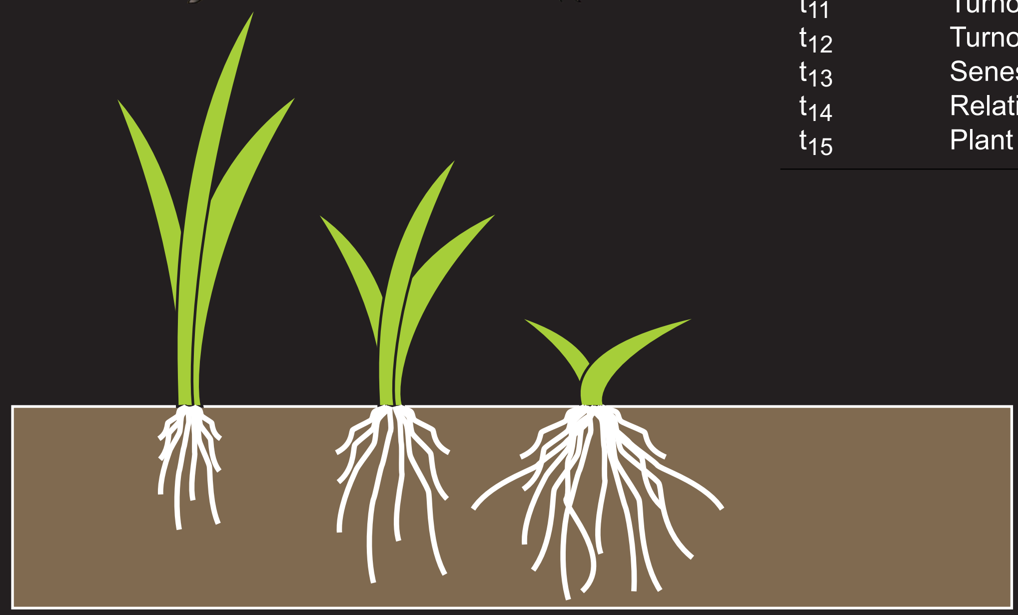


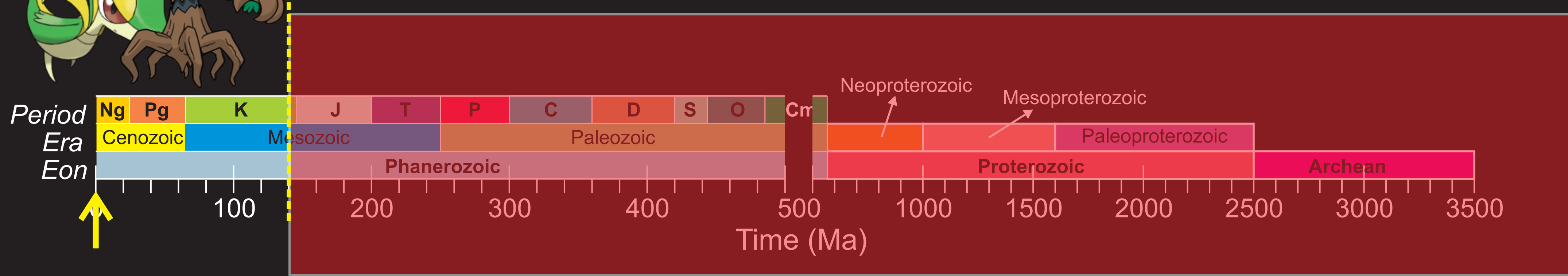
Controls on weathering *and the role of plants* (?)

Jena Diversity-Dynamic Global Vegetation Model (JeDi-DGVM)
[*Pavlick et al.*, 2013, *Biogeosciences*]

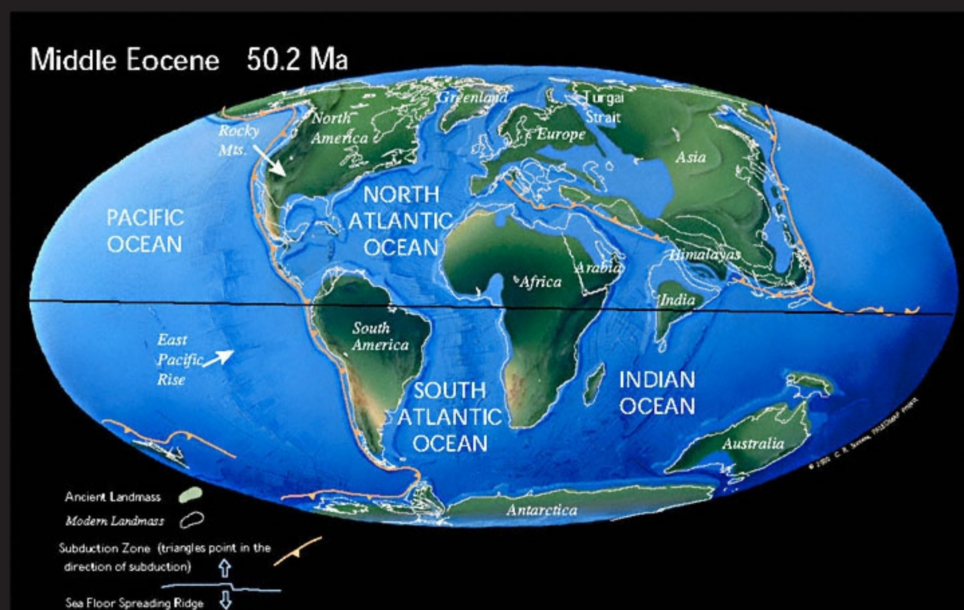
Table C2 Summary of the functional trait parameters.

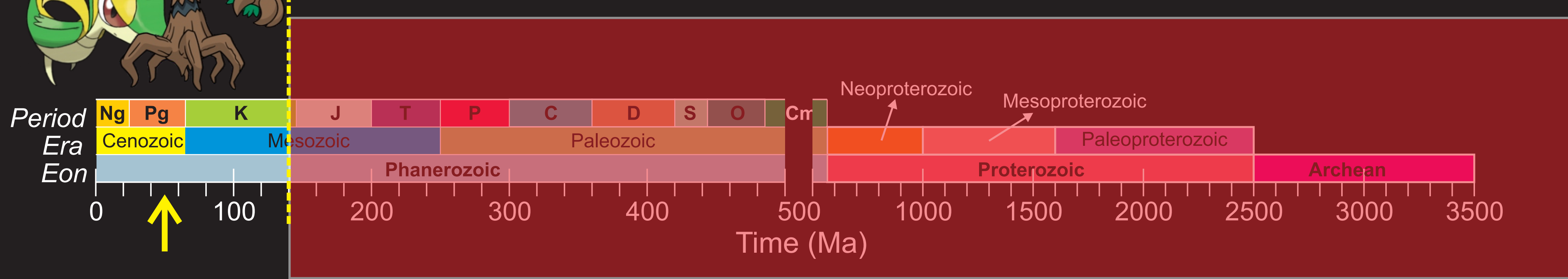
Parameter	Description
t_1	Growth response time to moisture conditions
t_2	Growth response time to temperature conditions
t_3	Critical temperature for growth
t_4	Germination fraction
t_5	Allocation to reproduction
t_6	Allocation to aboveground growth
t_7	Allocation to belowground growth
t_8	Allocation to storage
t_9	Relative allocation to aboveground structure
t_{10}	Relative allocation to belowground structure
t_{11}	Turnover time of structural pools
t_{12}	Turnover time of leaf and fine root pools
t_{13}	Senescence response time to productivity condition
t_{14}	Relative senescence aboveground
t_{15}	Plant nitrogen status





Controls on weathering *and the role of plants* (?)

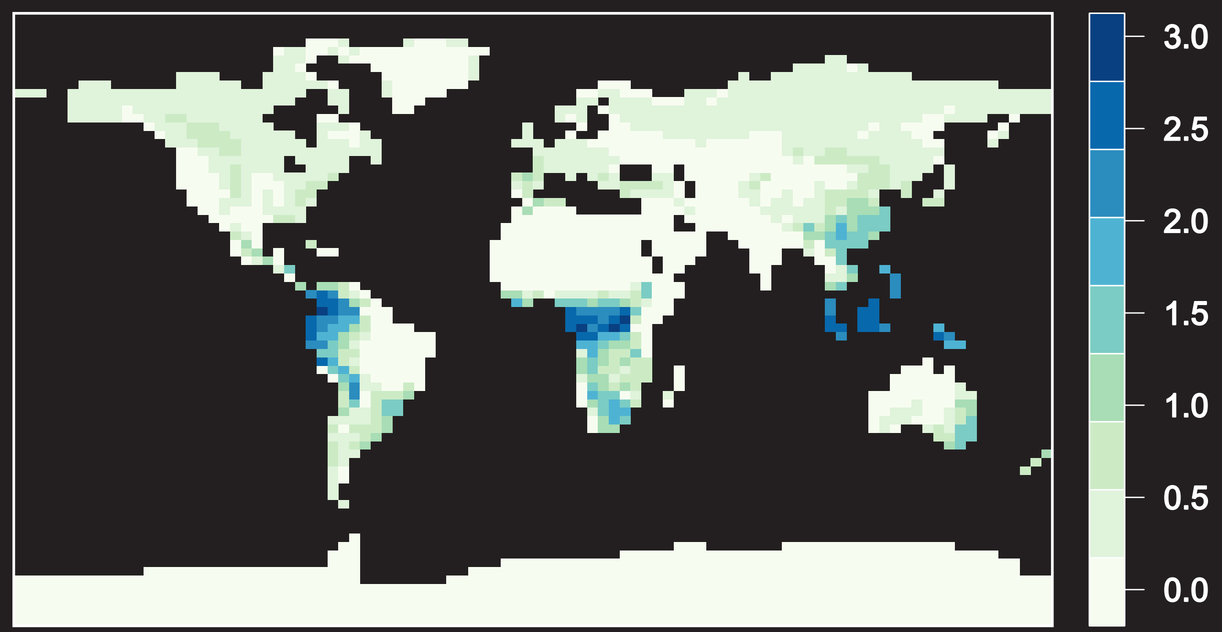


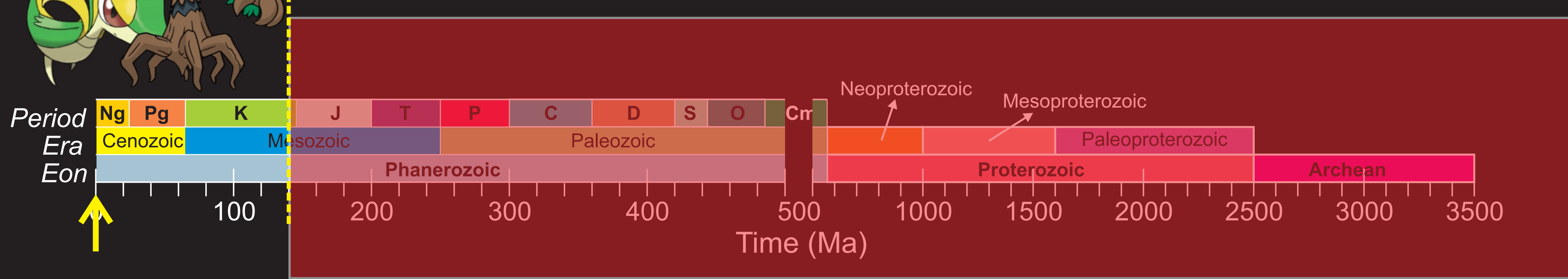


Controls on weathering *and the role of plants* (?)

pre-industrial climate, pCO_2 == 280 ppm

modern net primary productivity [gC m^{-2} day^{-1}]

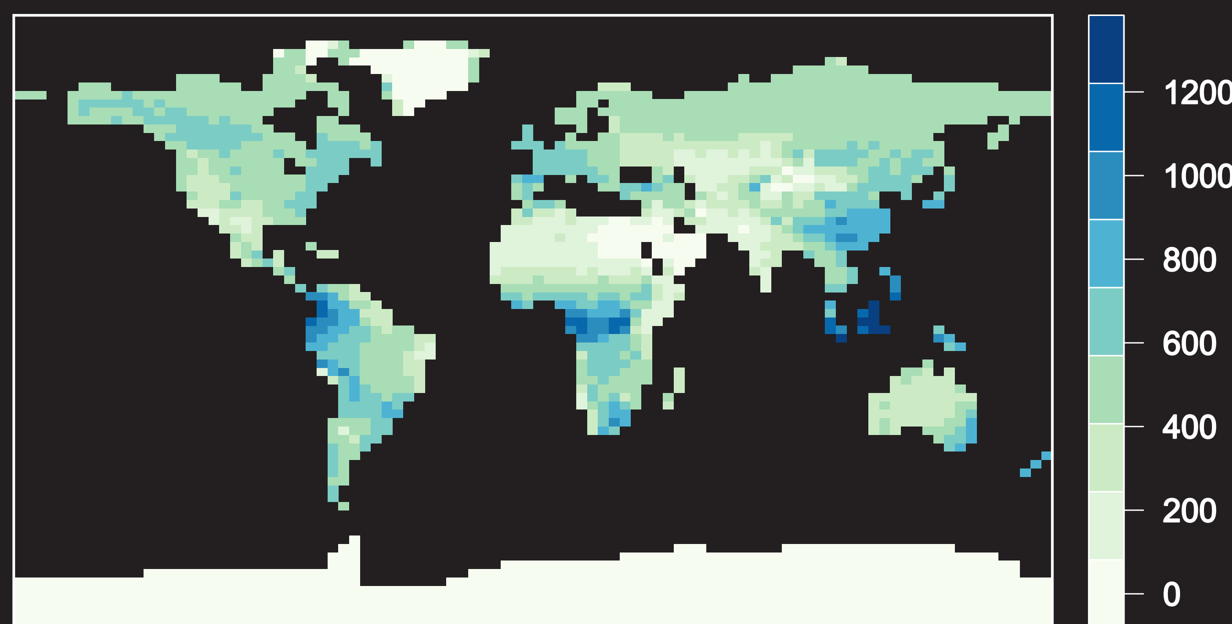


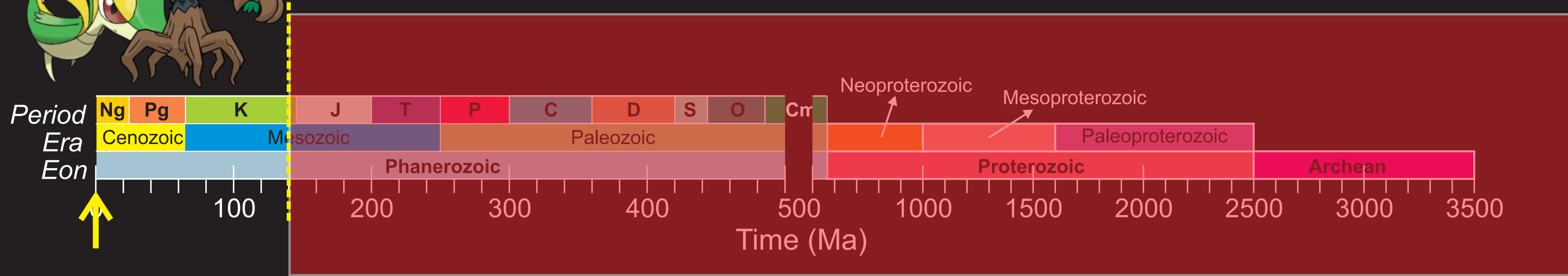


Controls on weathering *and the role of plants* (?)

pre-industrial climate, $p\mathrm{CO_2}$ == 280 ppm

modern functional richness [growth strategies]

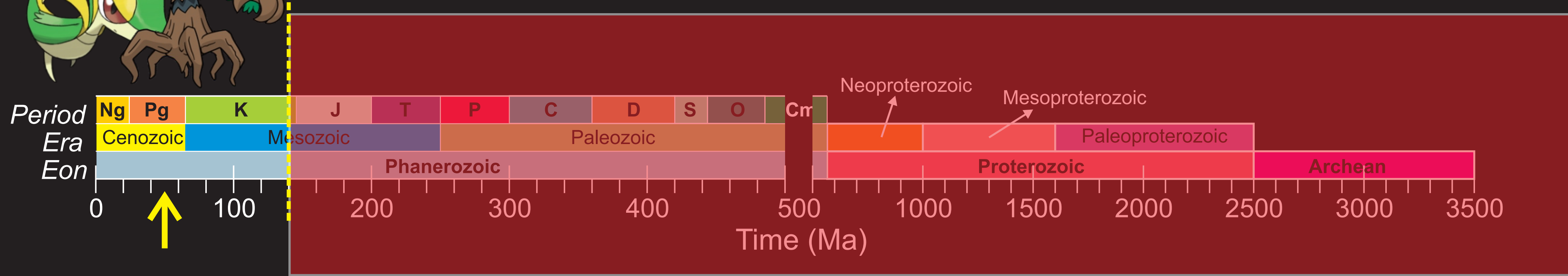




Controls on weathering *and the role of plants* (?)

x8 CO_2 climate, pCO_2 == 280 ppm

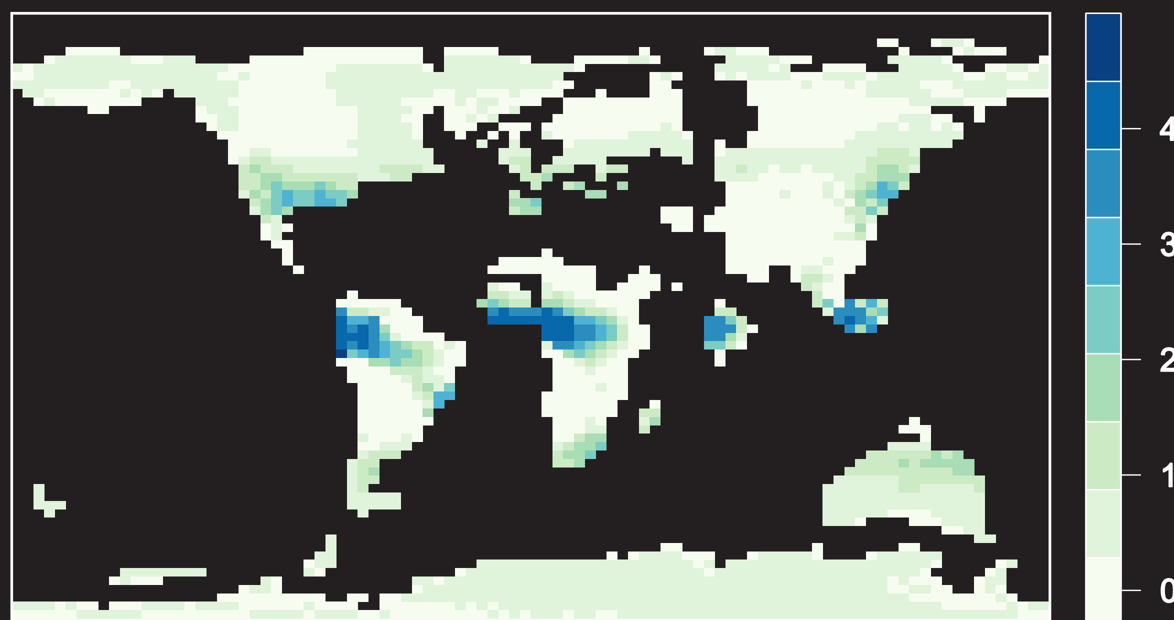
Ypresian net primary productivity [gC m^{-2} day^{-1}]

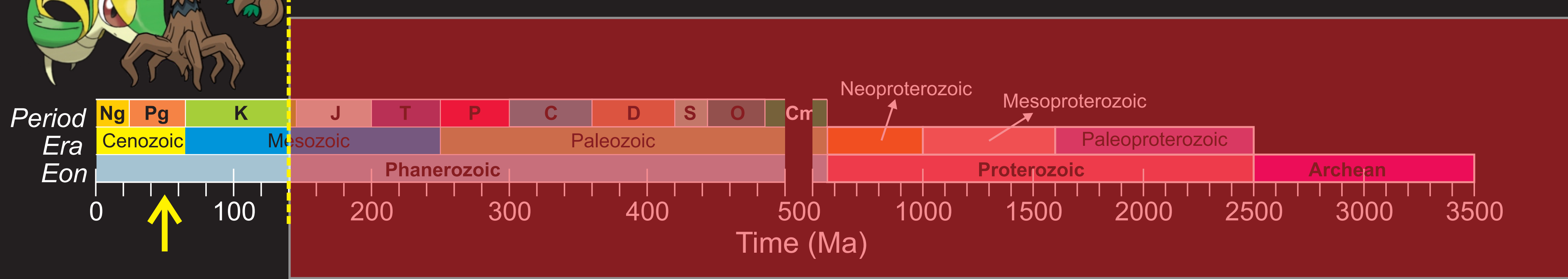


Controls on weathering *and the role of plants* (?)

x8 CO_2 climate, pCO_2 == 1680 ppm

Ypresian net primary productivity [gC m^{-2} day^{-1}]





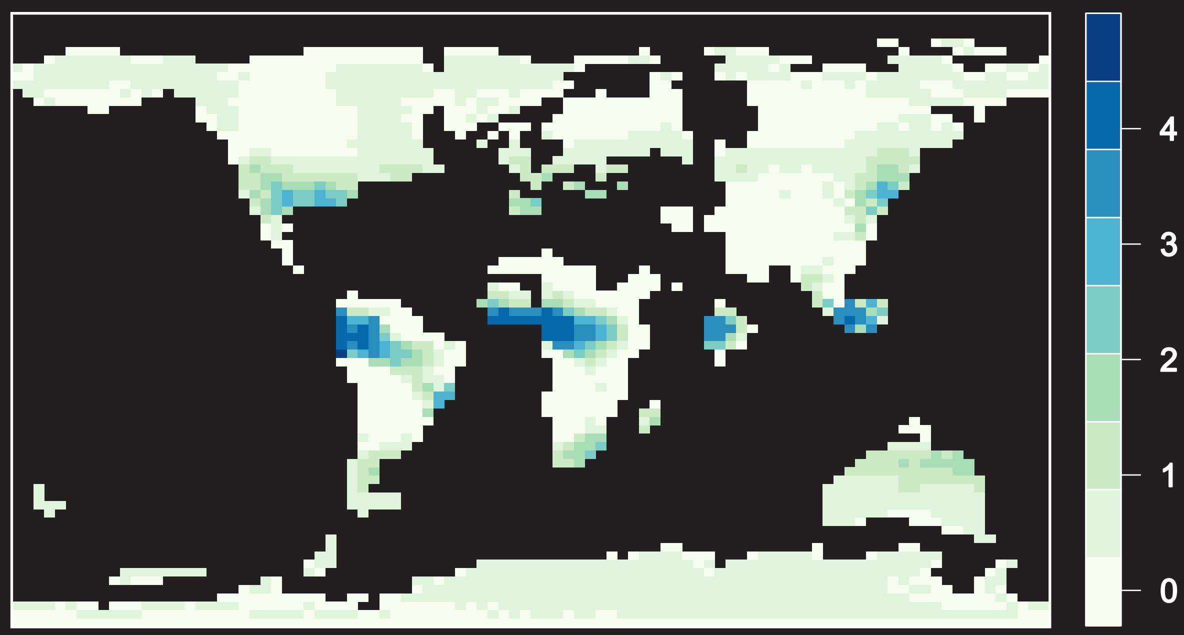
Controls on weathering *and the role of plants* (?)

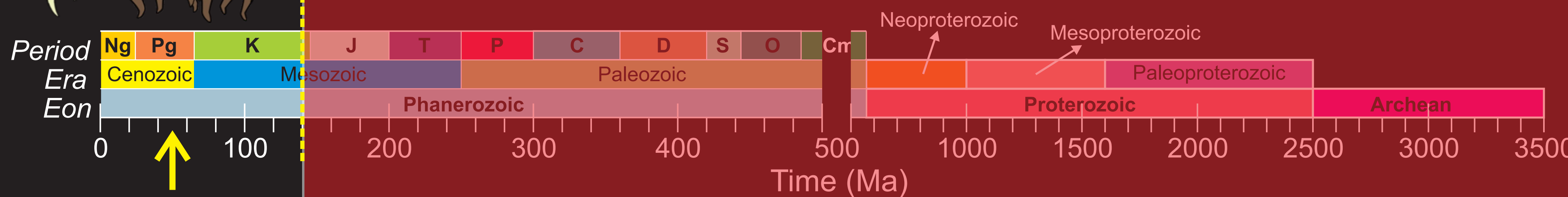
weathering ∝

f(soil properties, rock mineralogy) ⊗ f(hydrology, temperature, pCO_2) ⊗ f(plant productivity, plant type (roots))

x8 CO_2 climate, pCO_2 == 1680 ppm

Ypresian net primary productivity [gC m^{-2} day^{-1}]





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