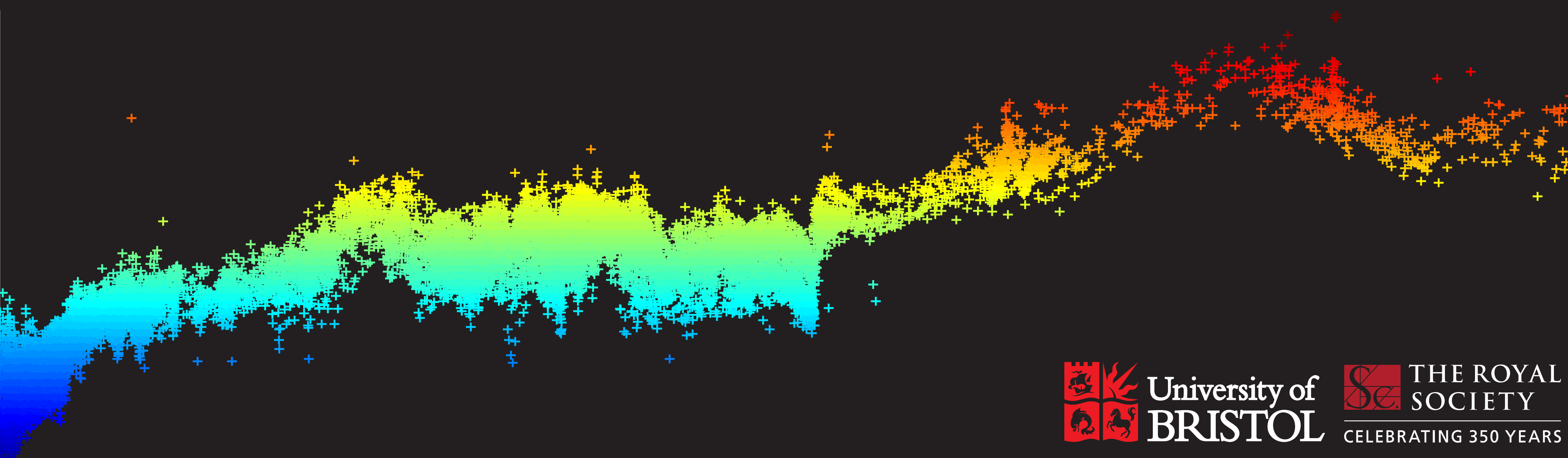
The Geological Record of Ocean Acidification

Andy Ridgwell

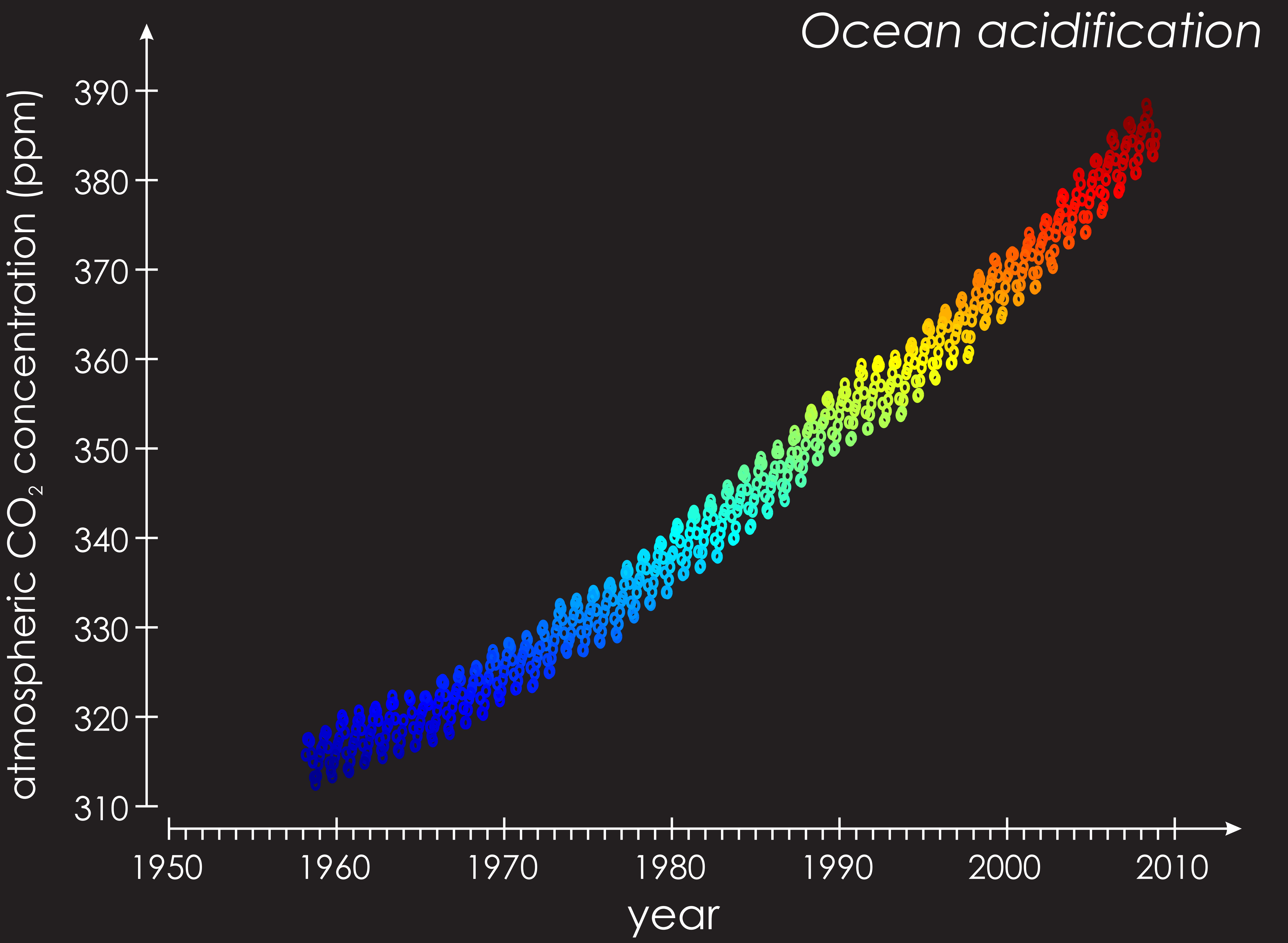


University of BRISTOL

THE ROYAL SOCIETY
CELEBRATING 350 YEARS


Google


UPS
POWER
3PIN



Ocean acidification
390
380
370
360
350
340
330
320
310
atmospheric CO_2 concentration (ppm)
1950
1960
1970
1980
1990
2000
2010
year

Ocean acidification

Brewer et al. [1999]

Mail Online

Rising carbon emissions could wipeout marine species with oceans acidifying at fastest rate

By Daily Mail Reporter

Last updated at 12:10 PM on 2nd March 2012

**How can anyone believe any thing these proven Liers have to say..just look at globle warming not one shread of Real proof that people have any thing to do with it..and now this...
If they want to keep there jobs that badly ,Do some real work...before starting to make up scare stores**

green_hackle, LONDON/ENGLAND, 03/3/2012 12:41

**Alarmist garbage.
This is all just guesses made from tiny samples of imperfect information by people who are looking for the answer they want to find.
None of them have any real evidence for what happened 300 years ago, never mind 300 million. It's 2+2=5 at its finest. They also always fail to mention that the causes of mass extinctions in prehistory are only theoretical, and that those extinctions took place over millions of years.
Any sense of any kind of impending disaster is just Hollywood hyperbole and fundraising. Even if any of what they say is true, there won't be any serious impact for the human race for millions of years, and there will be plenty of engineering and technological solutions before then.**

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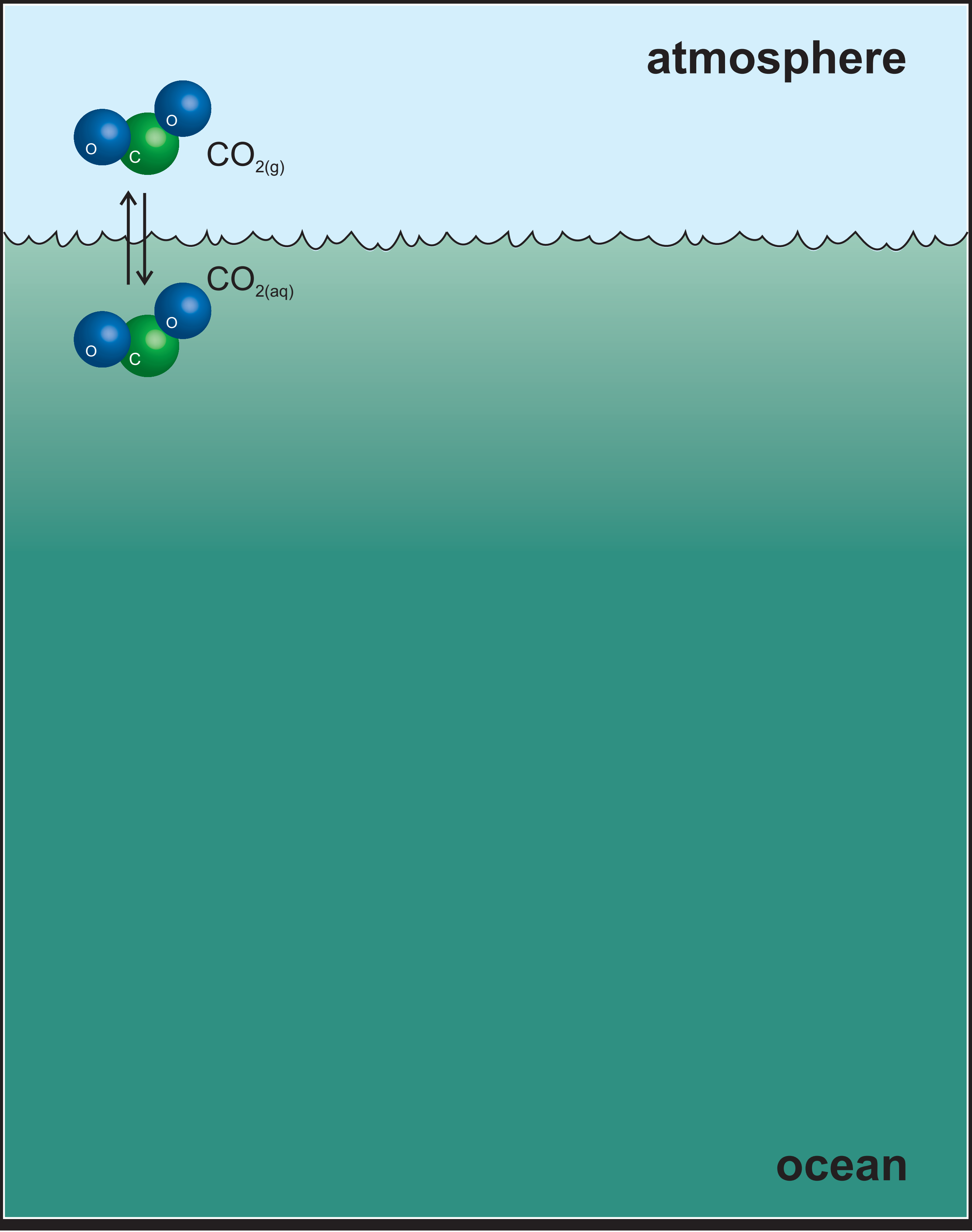
ChrisM, Ashford, England, 2/3/2012 12:07



CO_2 chemistry in seawater

From: *Barker and Ridgwell* [2012]
http://www.nature.com/scitable/knowledge/library/ocean-acidification-25822734

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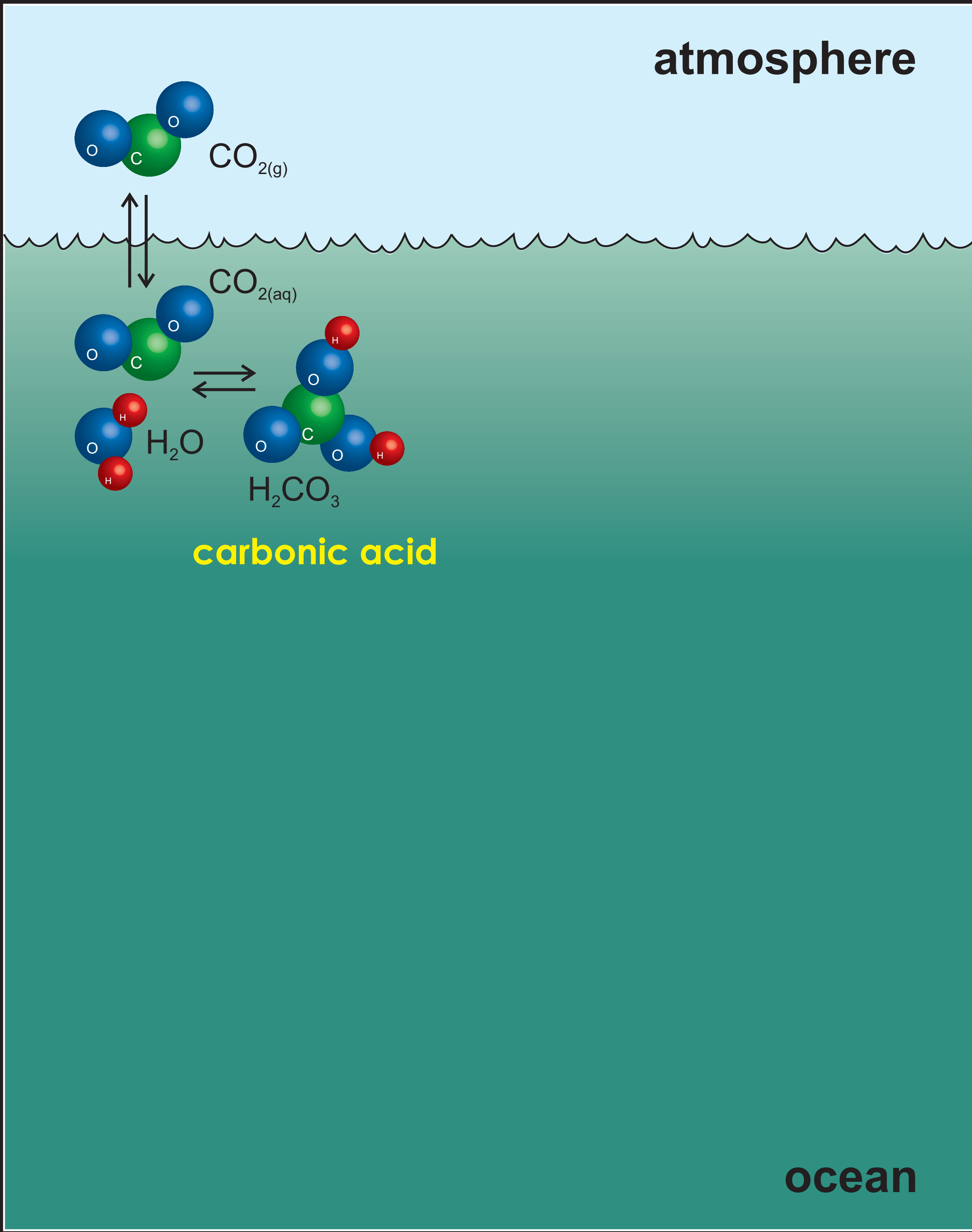

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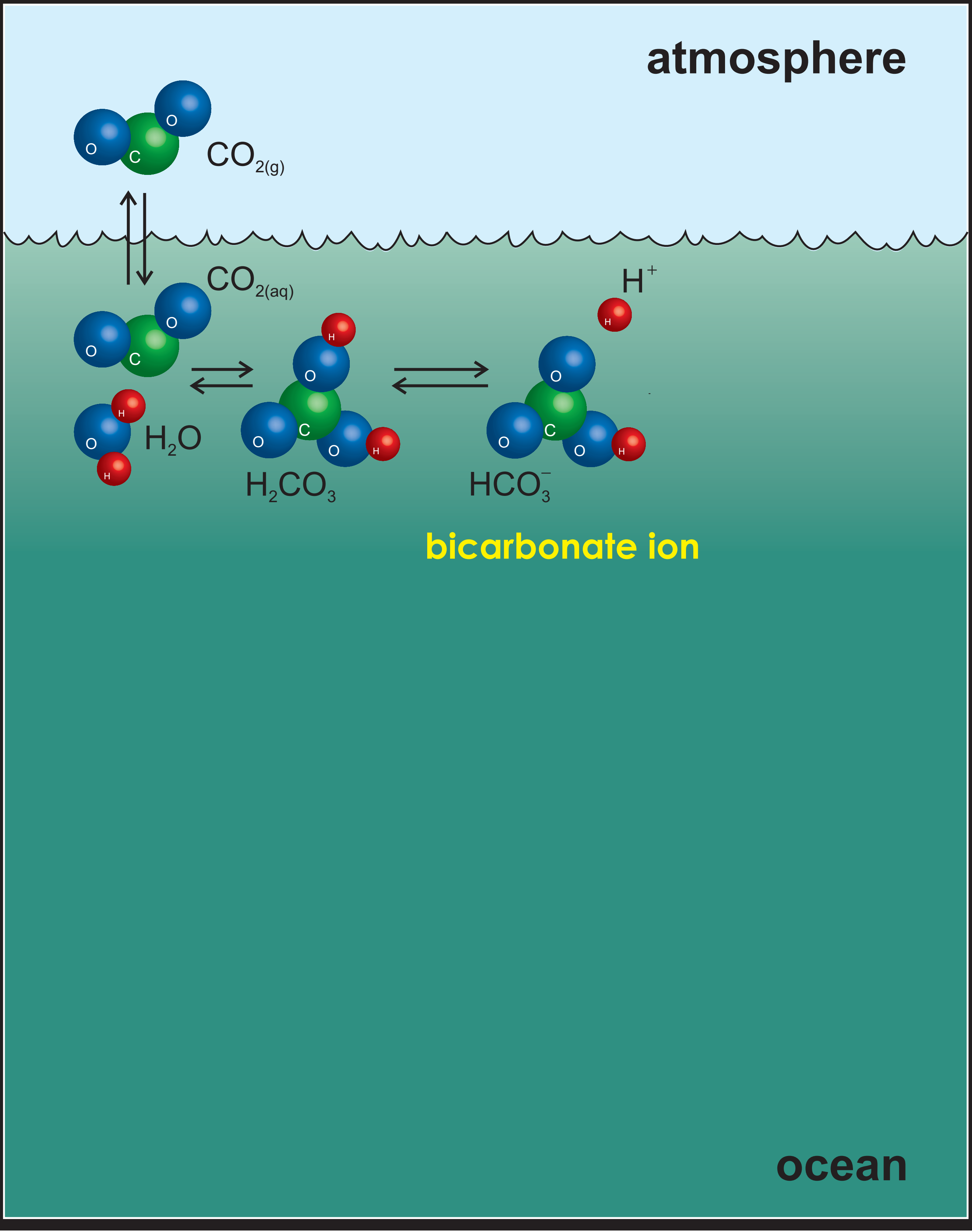

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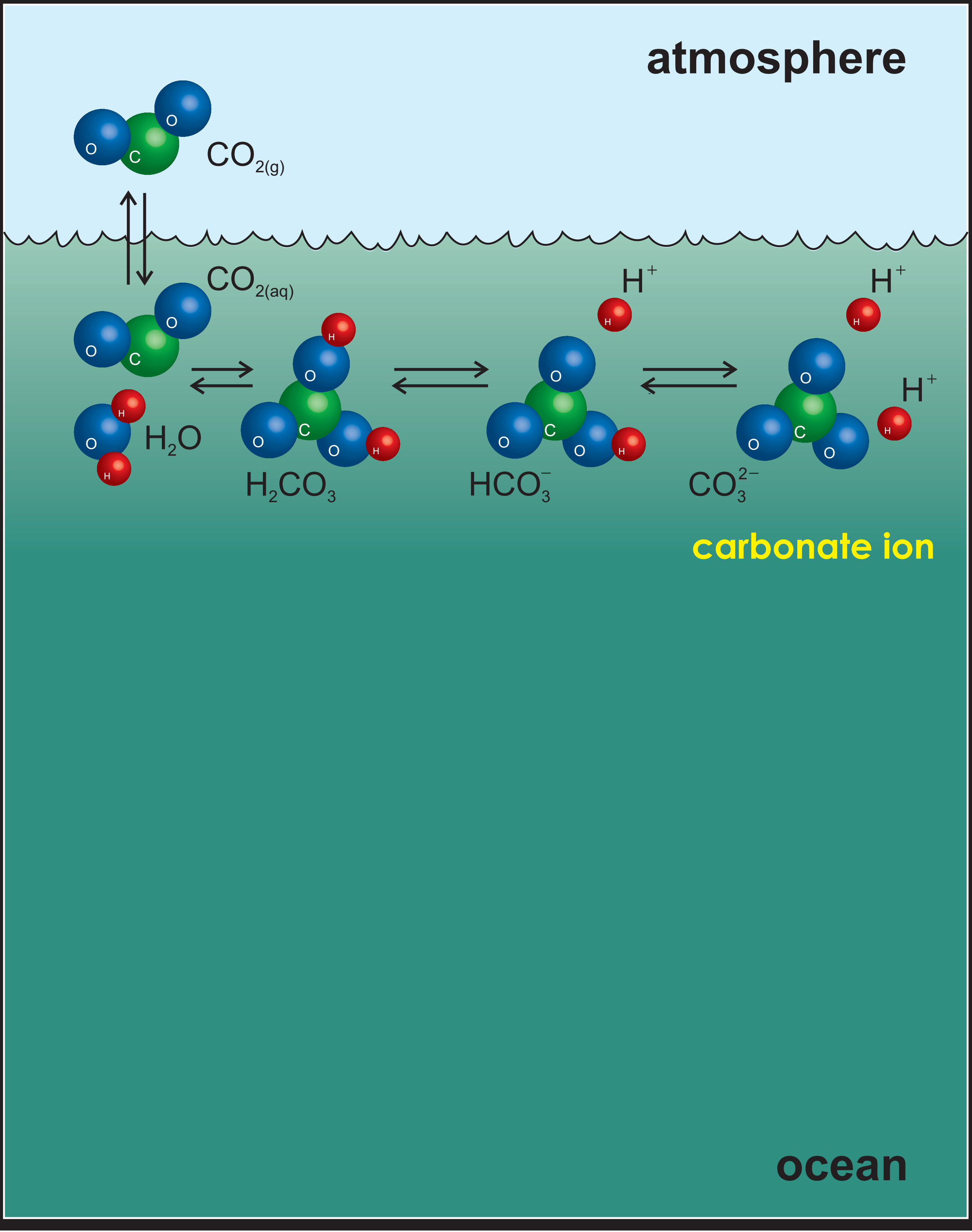
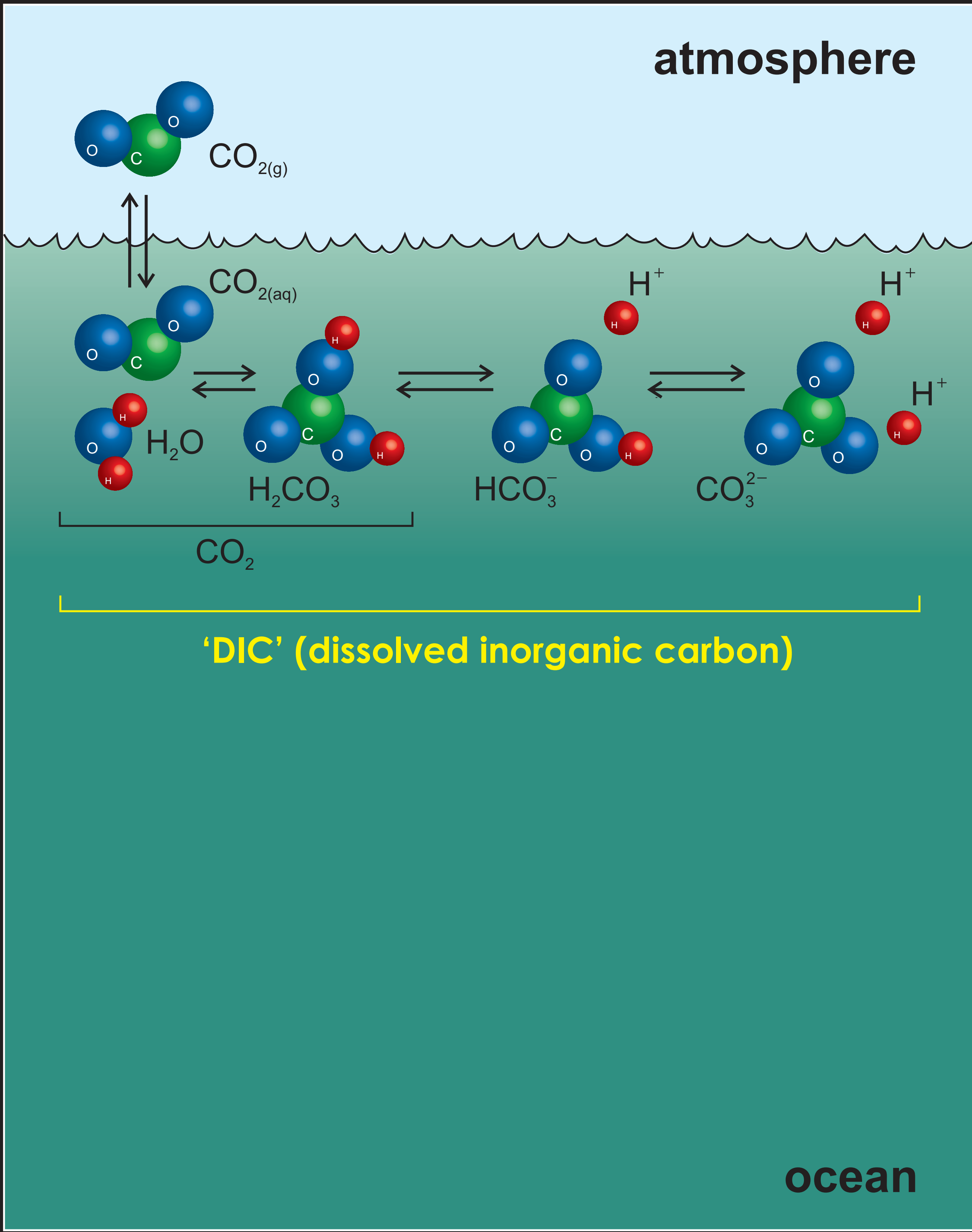




CO_2 chemistry in seawater

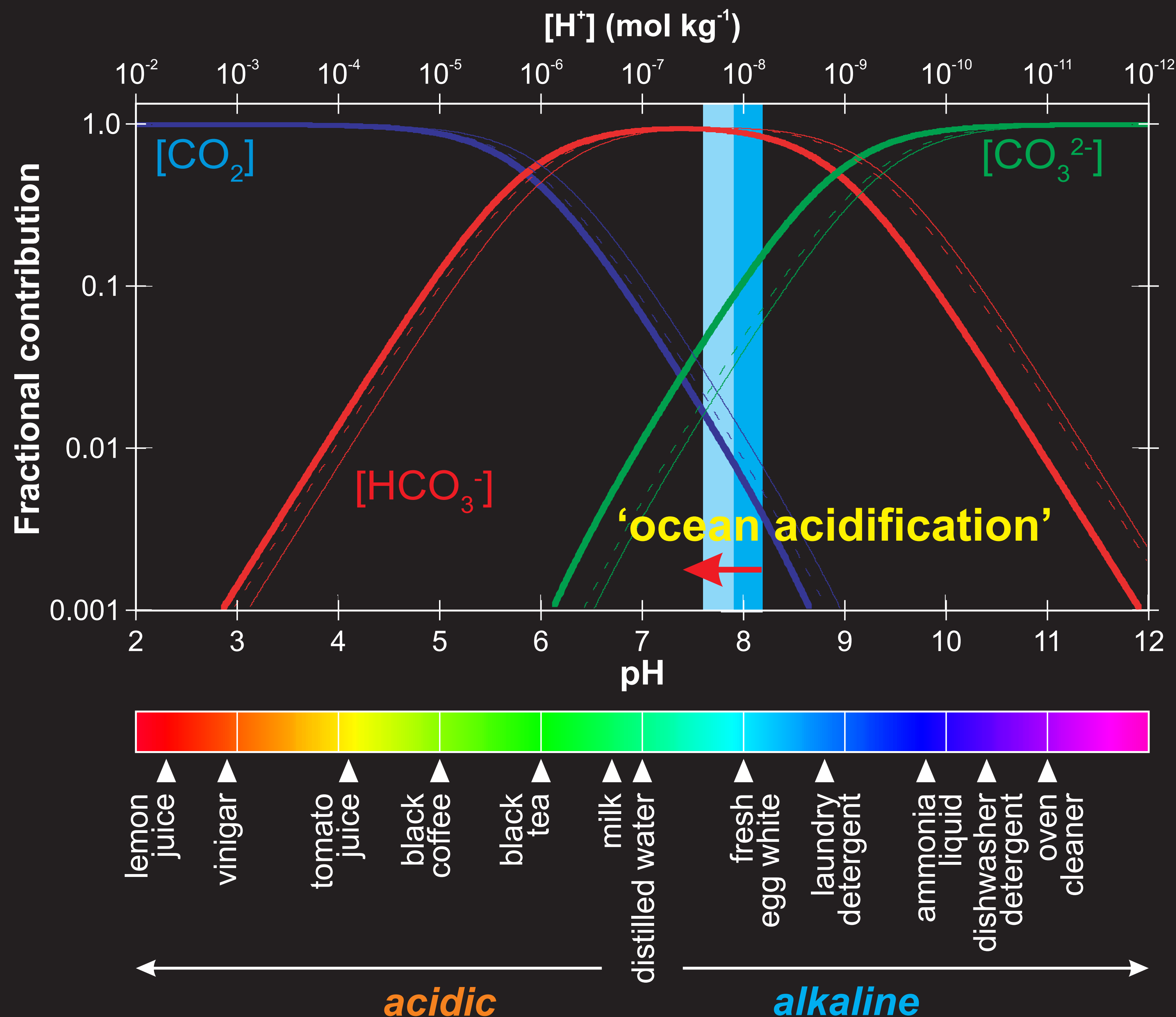
When CO_2 dissolves in seawater, the equilibrium distribution of dissolved carbon between $CO_{2(aq)}$, HCO_3^-, and CO_3^{2-}, is perturbed.

To a first approximation, the net outcome can be written:

$$CO_{2(aq)} + CO_3^{2-} + H_2O \rightarrow 2HCO_3^-$$

(However, a small part of the resulting HCO_3^- dissociates into CO_3^{2-} and H^+, which is where the 'acidification' in ocean acidification comes from.)

The nature of pH (and acidity vs. alkalinity)



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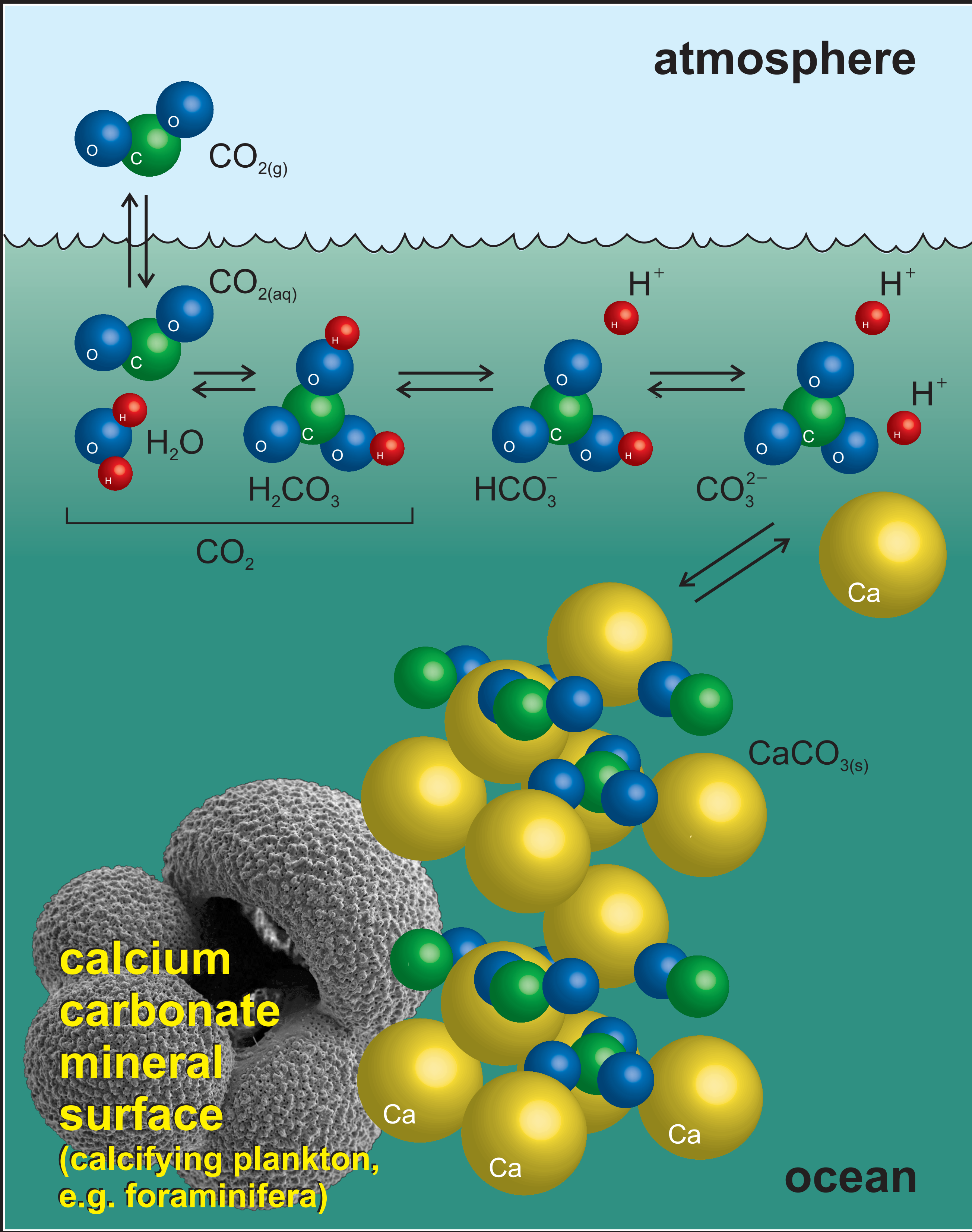


CO_2 chemistry & mineral phases

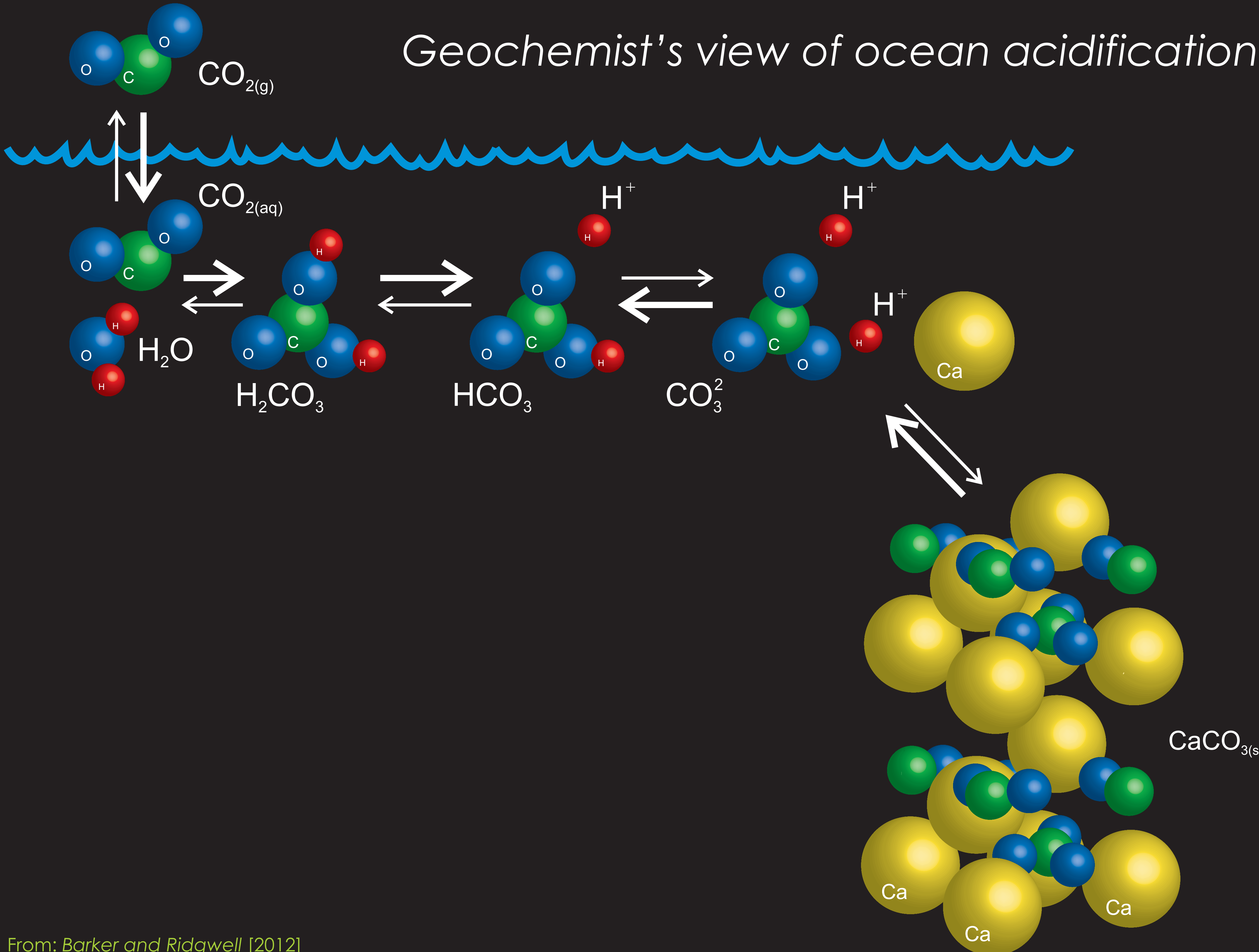
In decreasing the ocean carbonate ion (CO_3^{2-}) concentration, the stability of $CaCO_3$, defined by its *saturation state*:

$$\Omega = [Ca^{2+}]\times[CO_3^{2-}]\,/k$$

is suppressed.

Ω is simply a (normalized) measure of how thermodynamically favourable it is to precipitate $CaCO_3$.

Geochemist's view of ocean acidification



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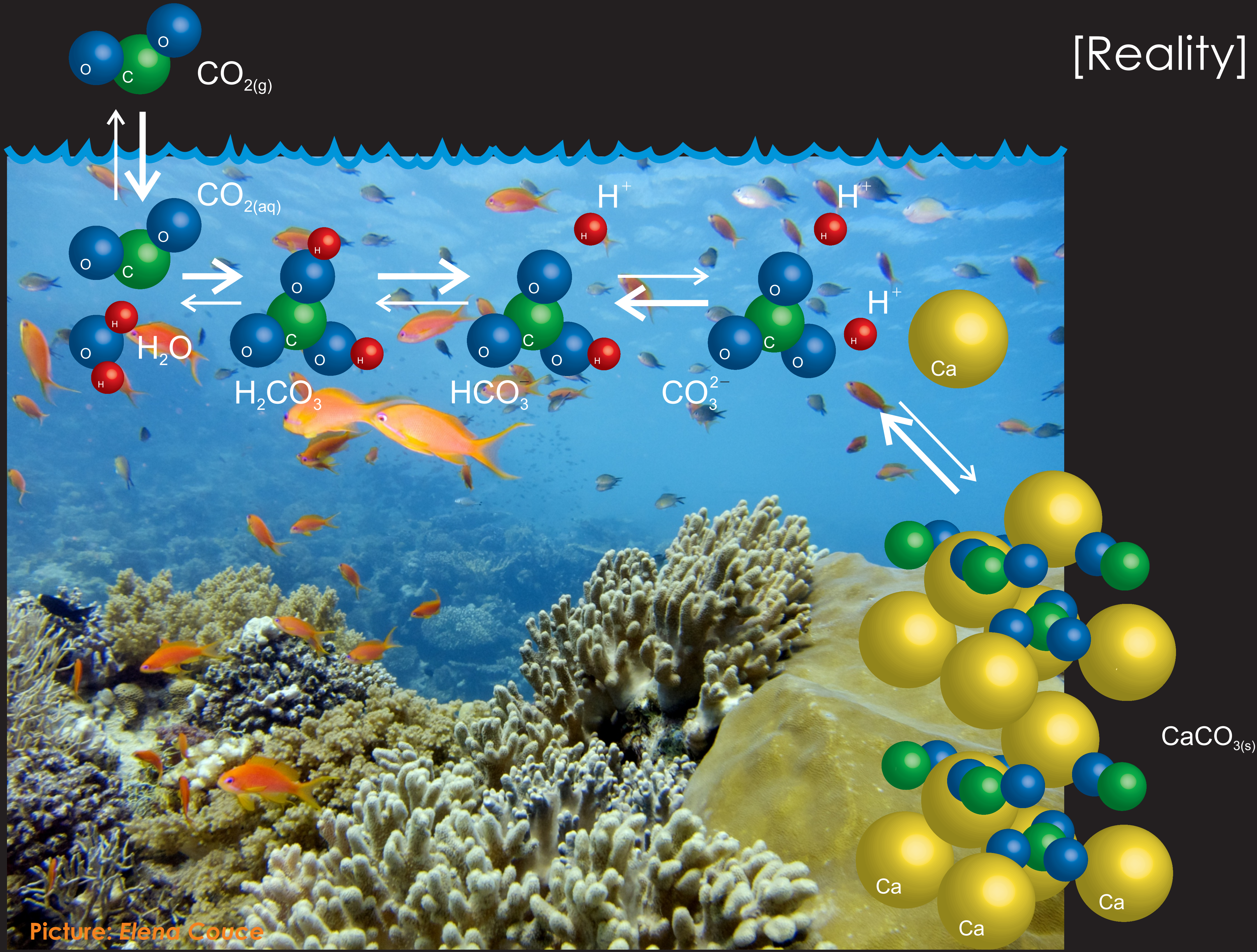
[Reality]

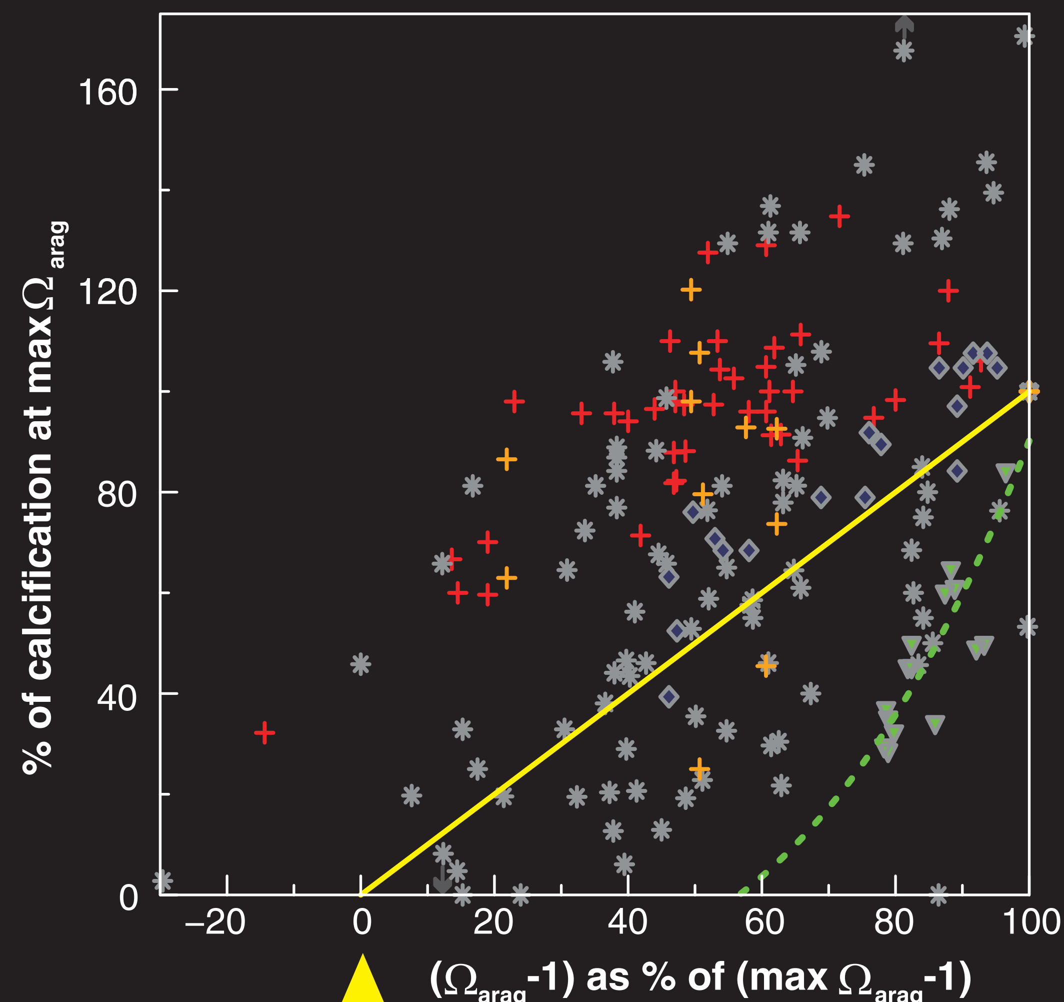


$CO_{2(g)}$
$CO_{2(aq)}$
H_2O
H_2CO_3
HCO_3^-
CO_3^{2-}
H^+
H^+
H^+
Ca
$CaCO_{3(s)}$
Ca
Ca
Ca
Picture: Elena Couce

Ocean biological consequences(?)

decreasing pH, saturation

decreasing calcification



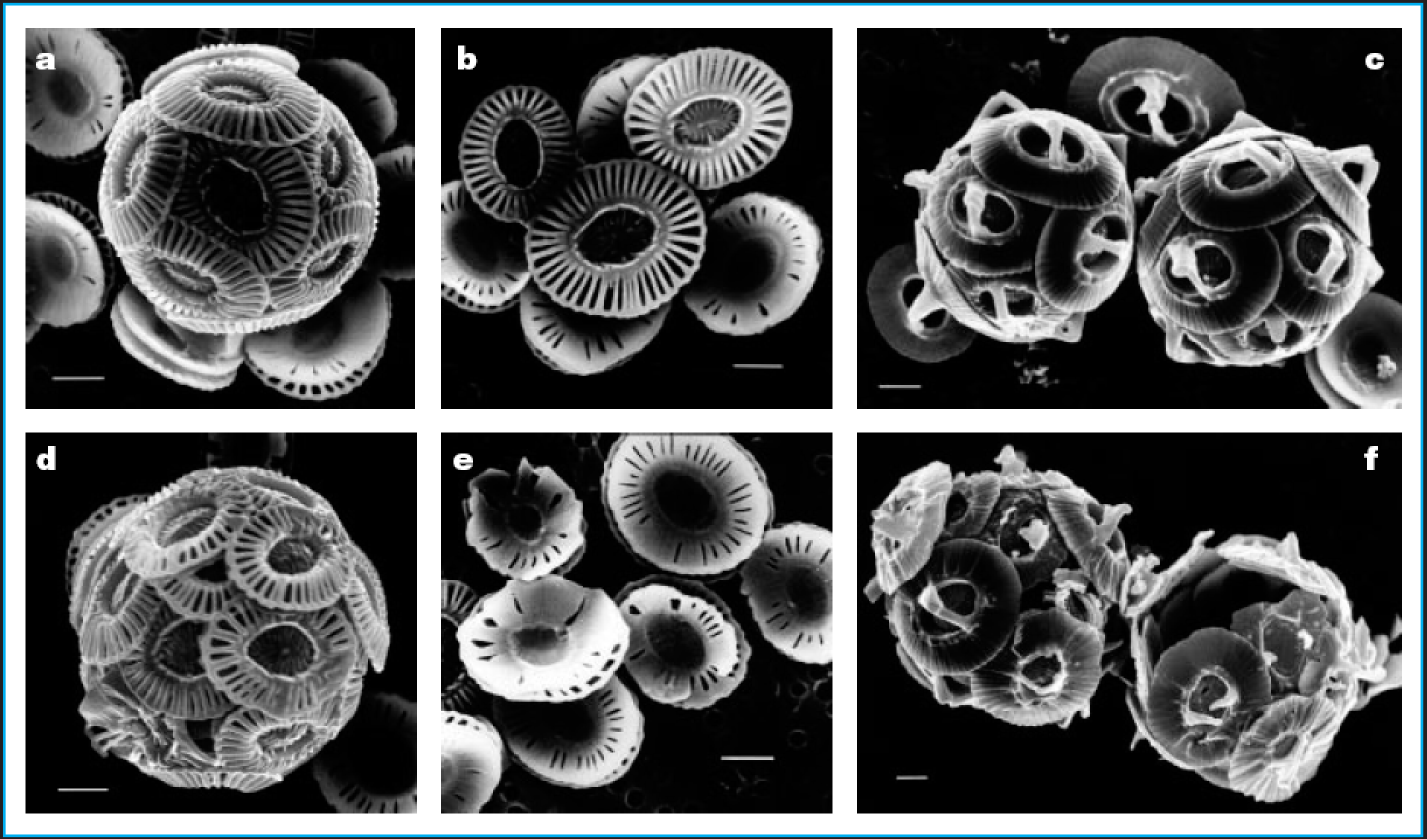
under-saturated

$\Omega = 1.0$

over-saturated

Pandolfi et al. [2011] (*Science*)

Ocean biological consequences(?)

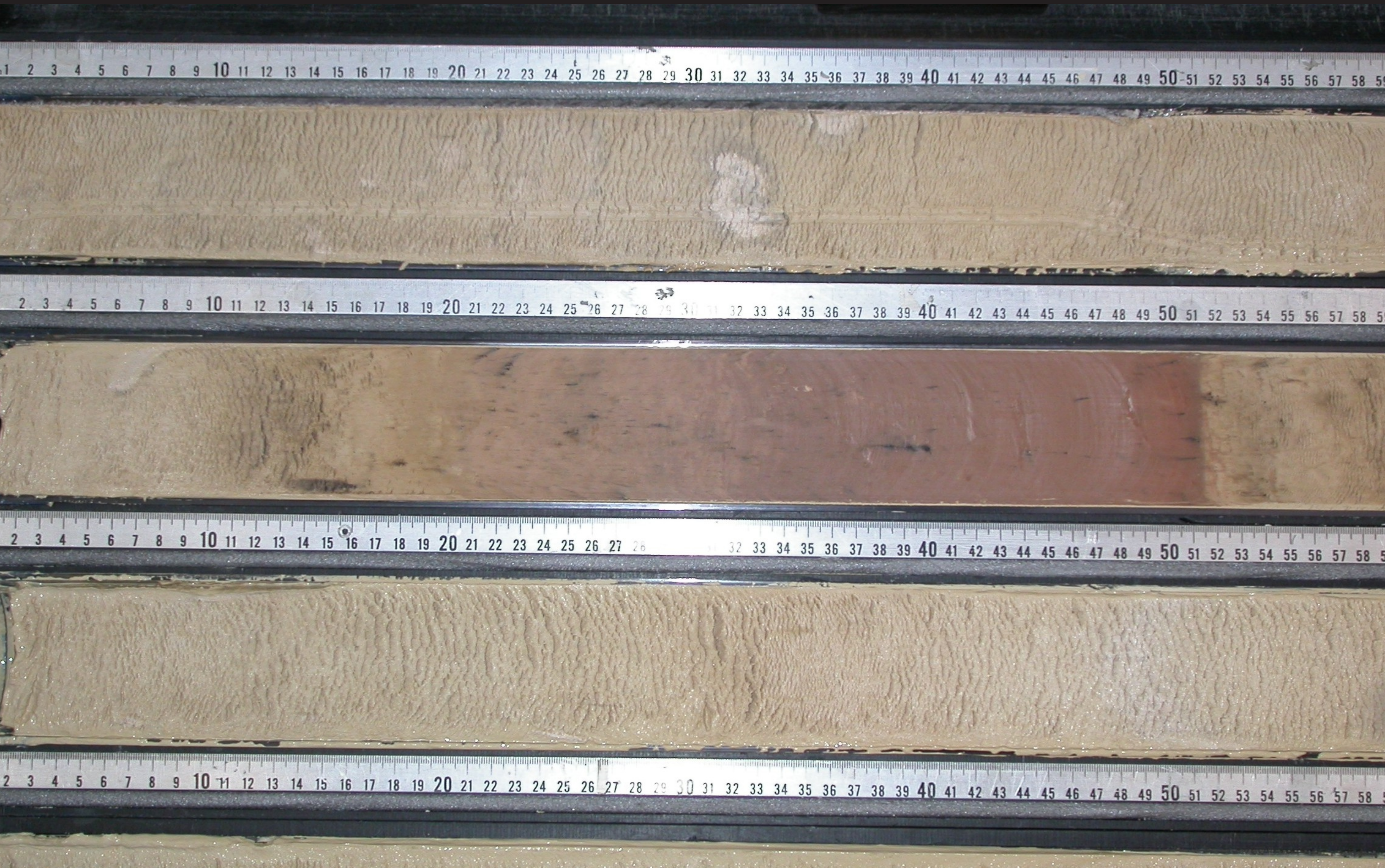


low CO_2 (high pH)

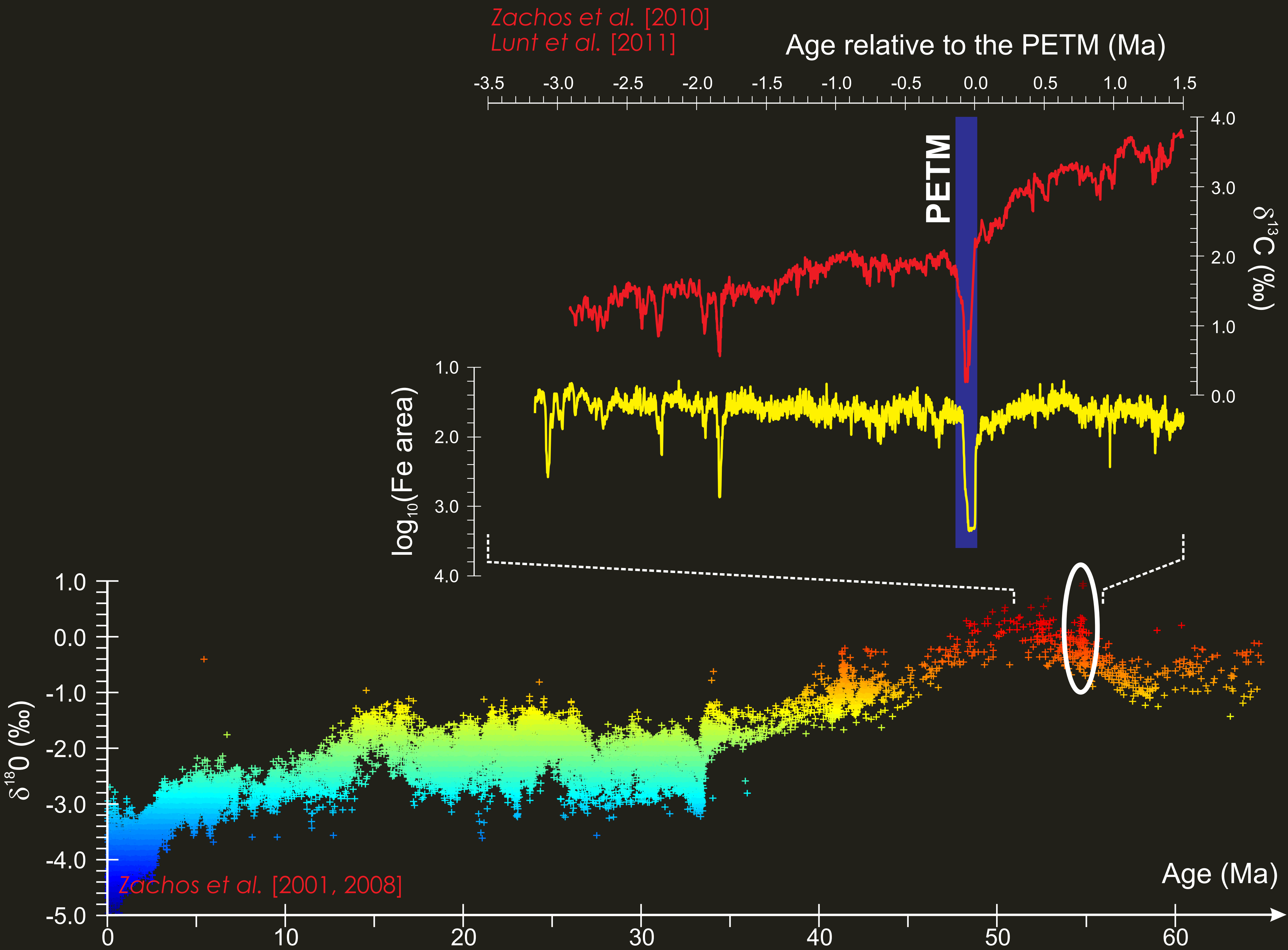
high CO_2 (low pH)

SEM micrographs of coccolithophorids under different CO_2 conditions
Riebesell et al. [2000] (*Nature* 407)

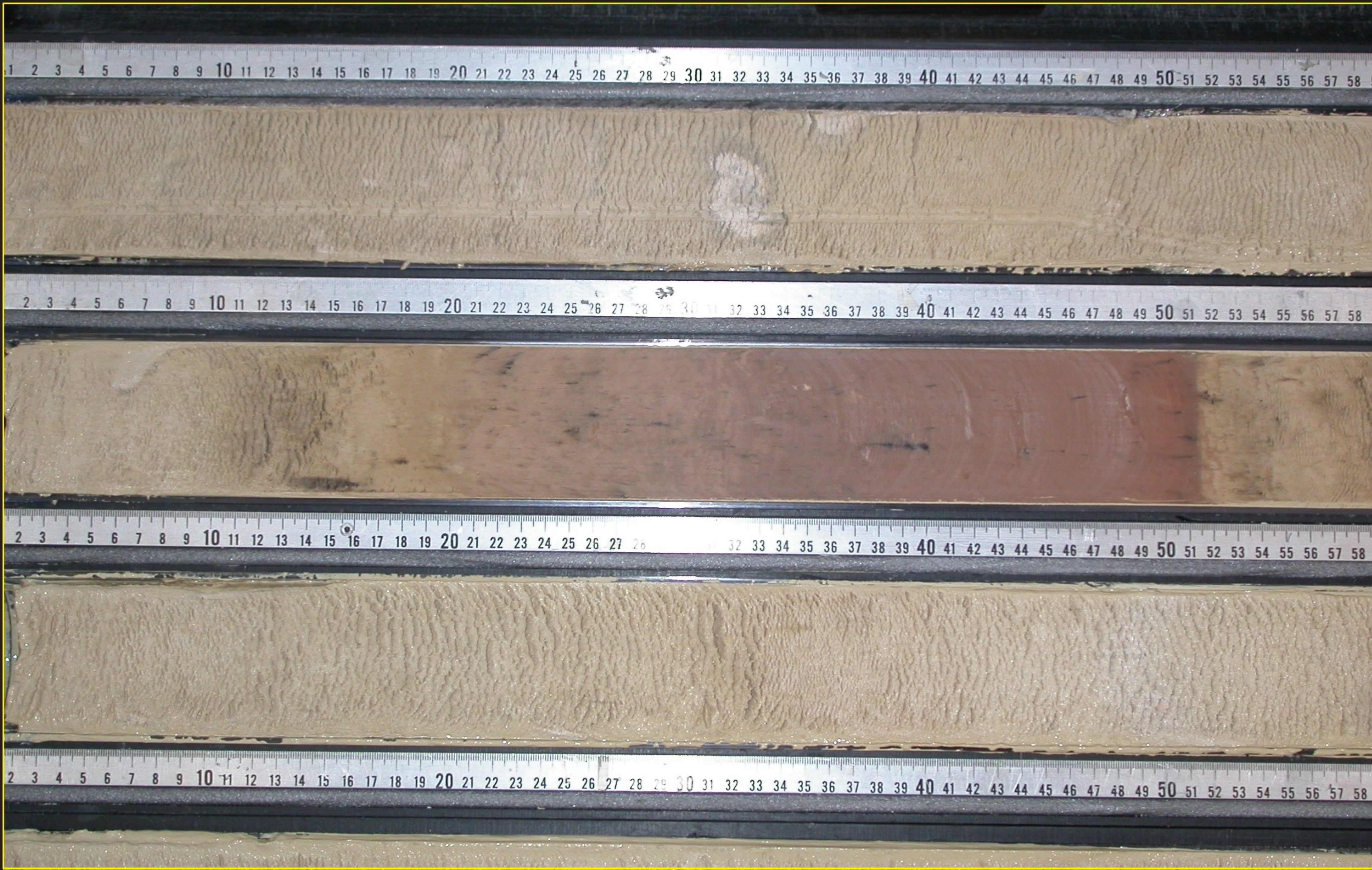
The geological record of ocean acidification



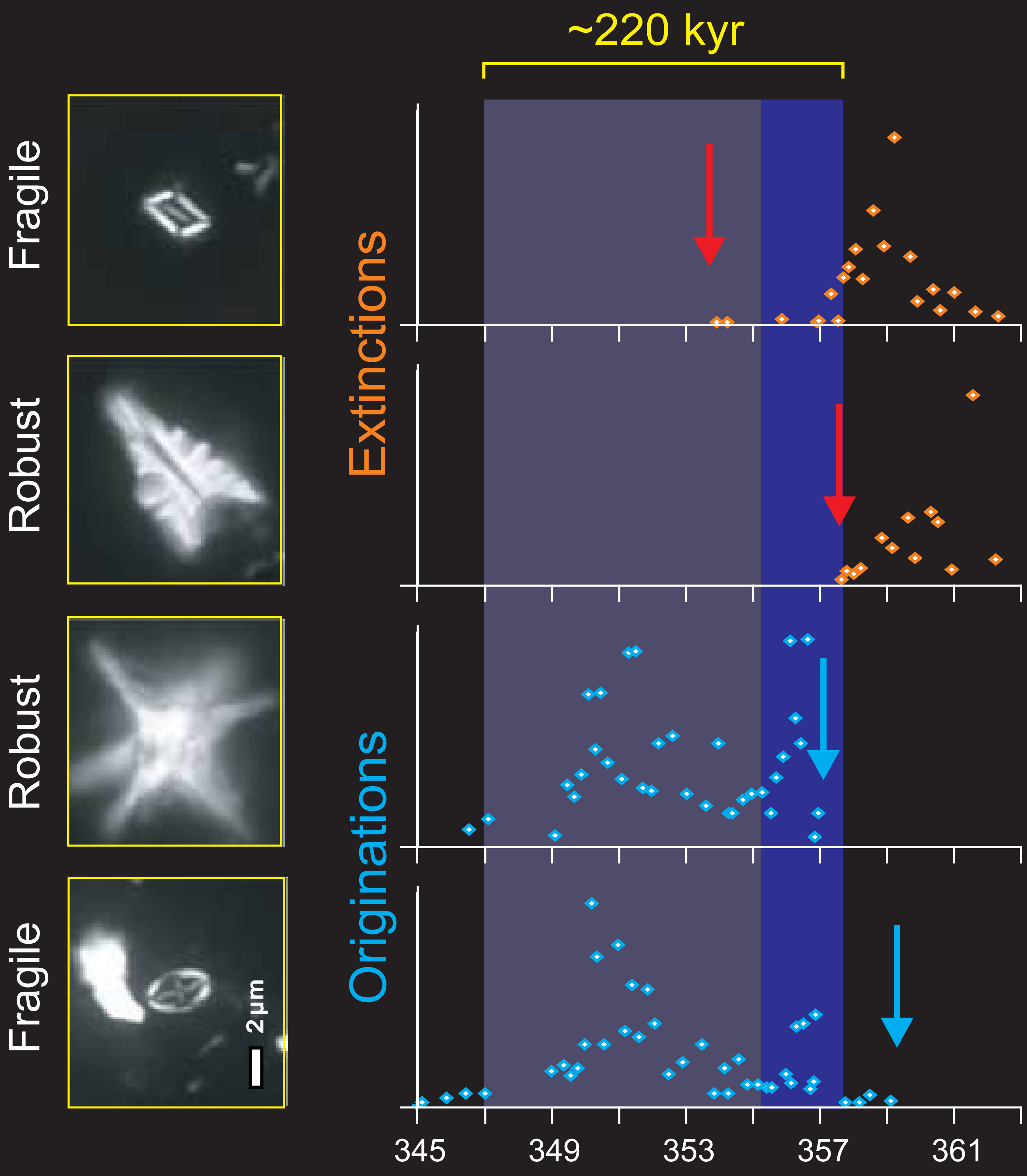

JOIDES Resolution

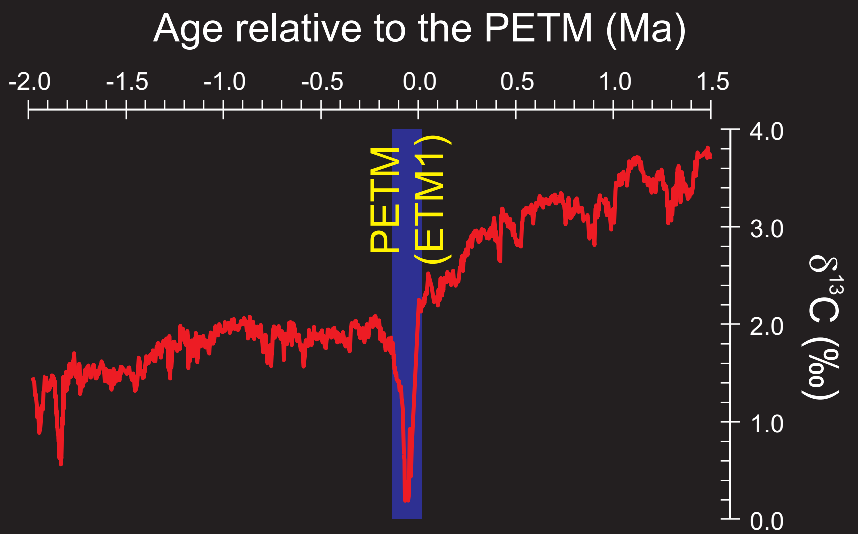


Zachos et al. [2010]
Lunt et al. [2011]
Age relative to the PETM (Ma)
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
PETM
4.0
3.0
2.0
1.0
0.0
δ13C (‰)
log10(Fe area)
1.0
2.0
3.0
4.0
δ18O (‰)
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
Zachos et al. [2001, 2008]
Age (Ma)
0
10
20
30
40
50
60



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

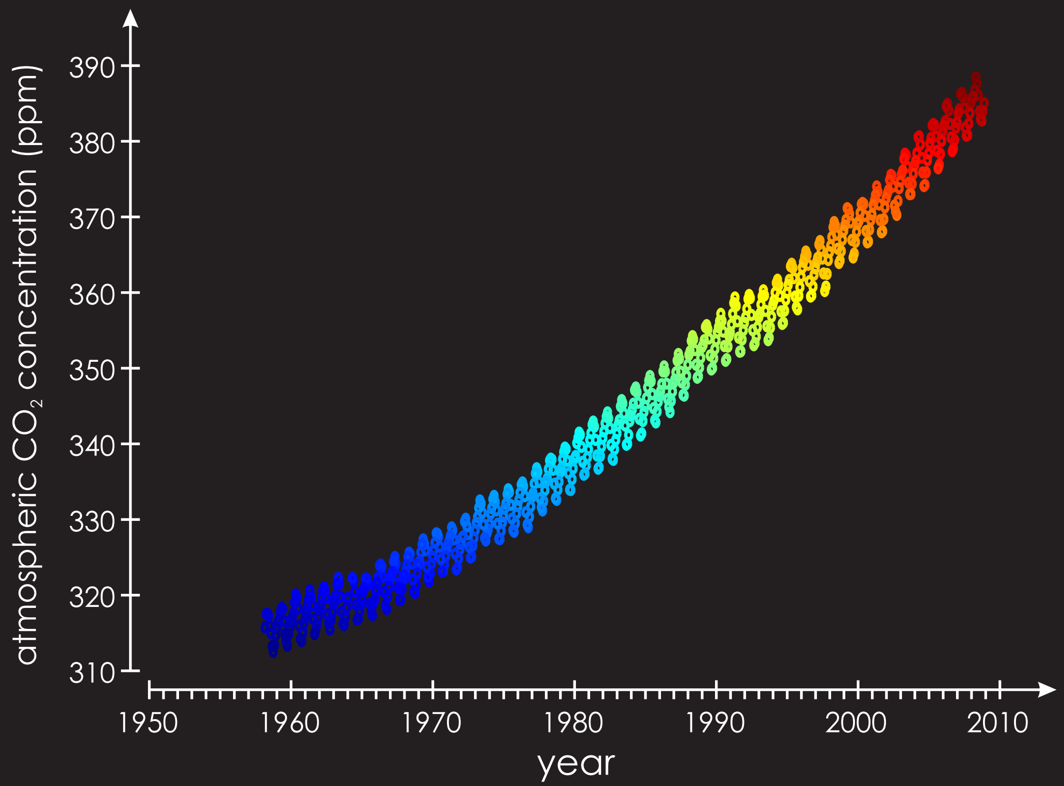


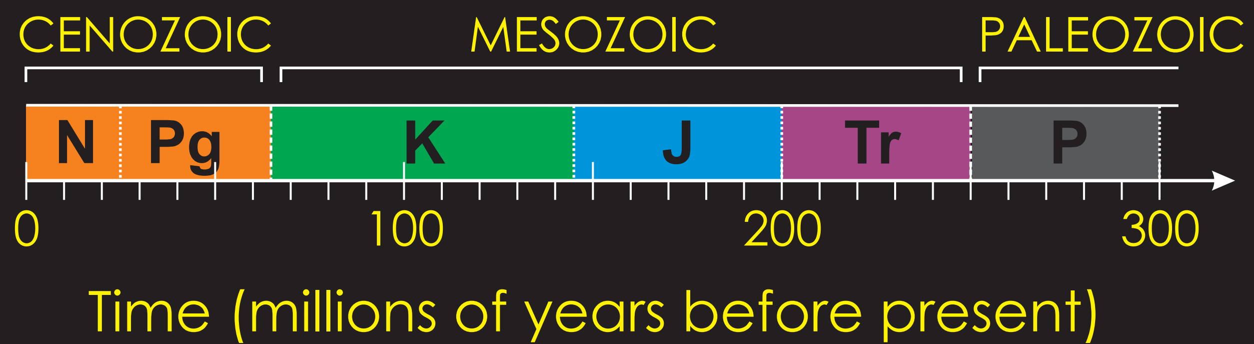


observed nanoplankton assemblage response to environmental change across the PETM

Gibbs et al. [2006] (*Science*)

The Geological Record of Ocean Acidification





From: *Hönisch et al.* [2012]

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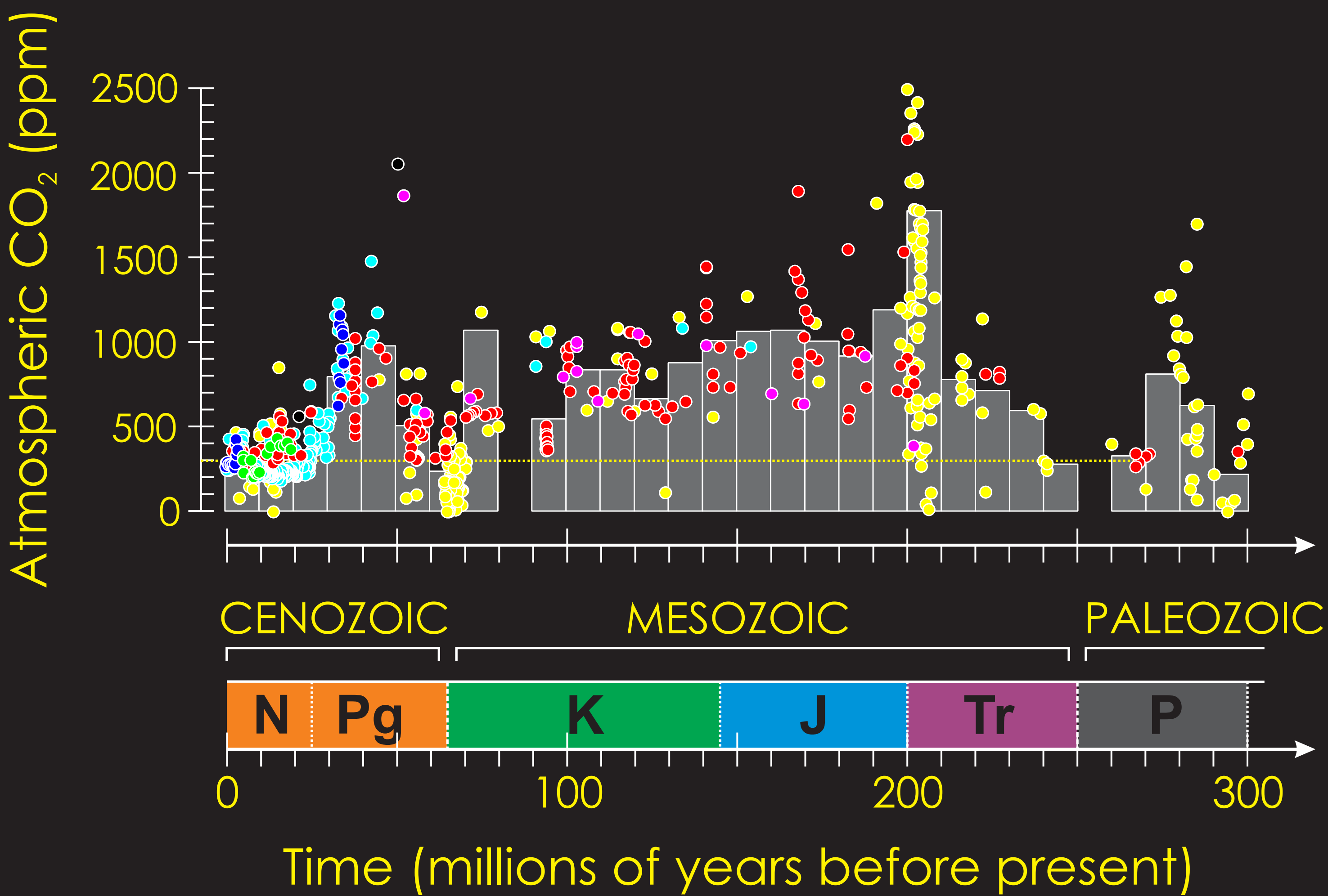

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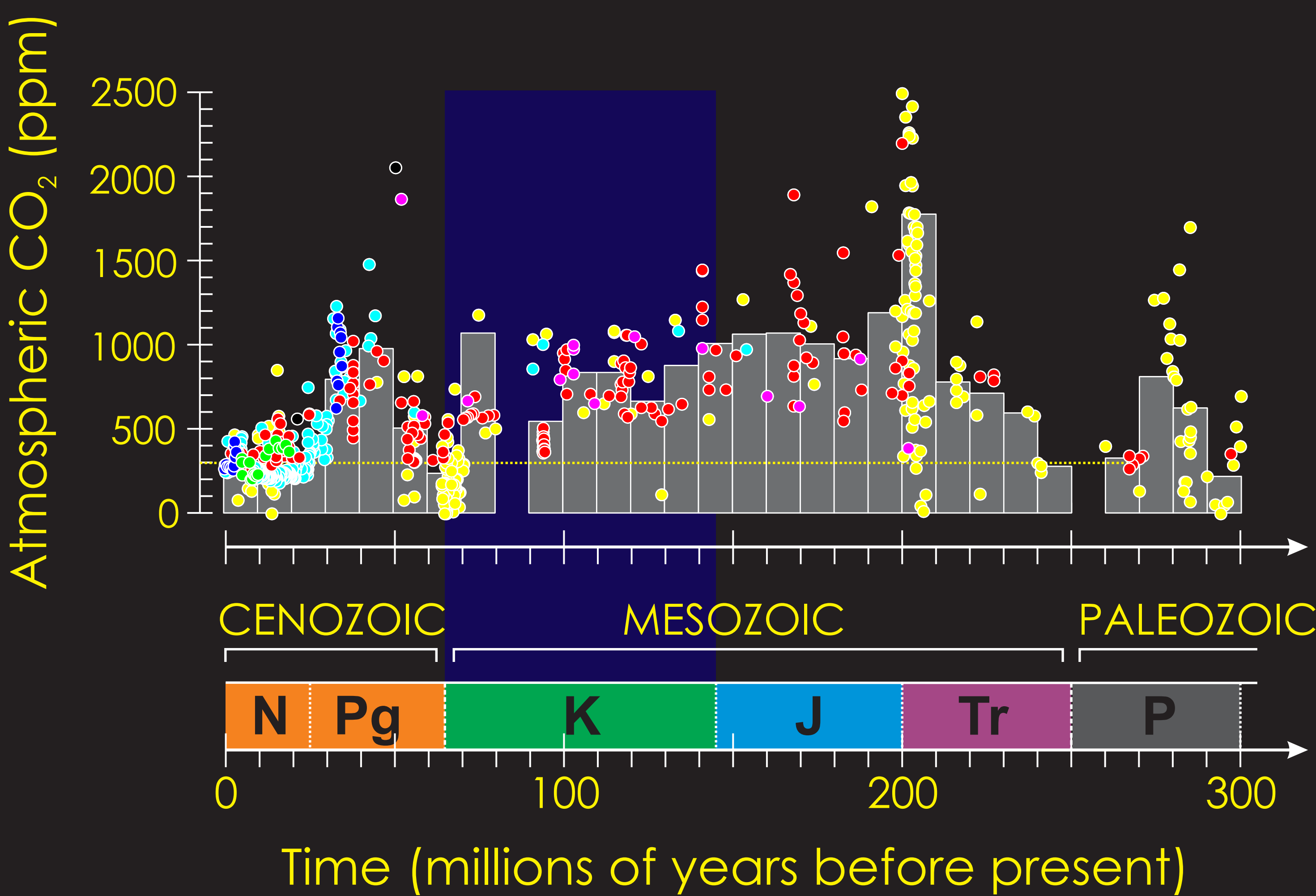

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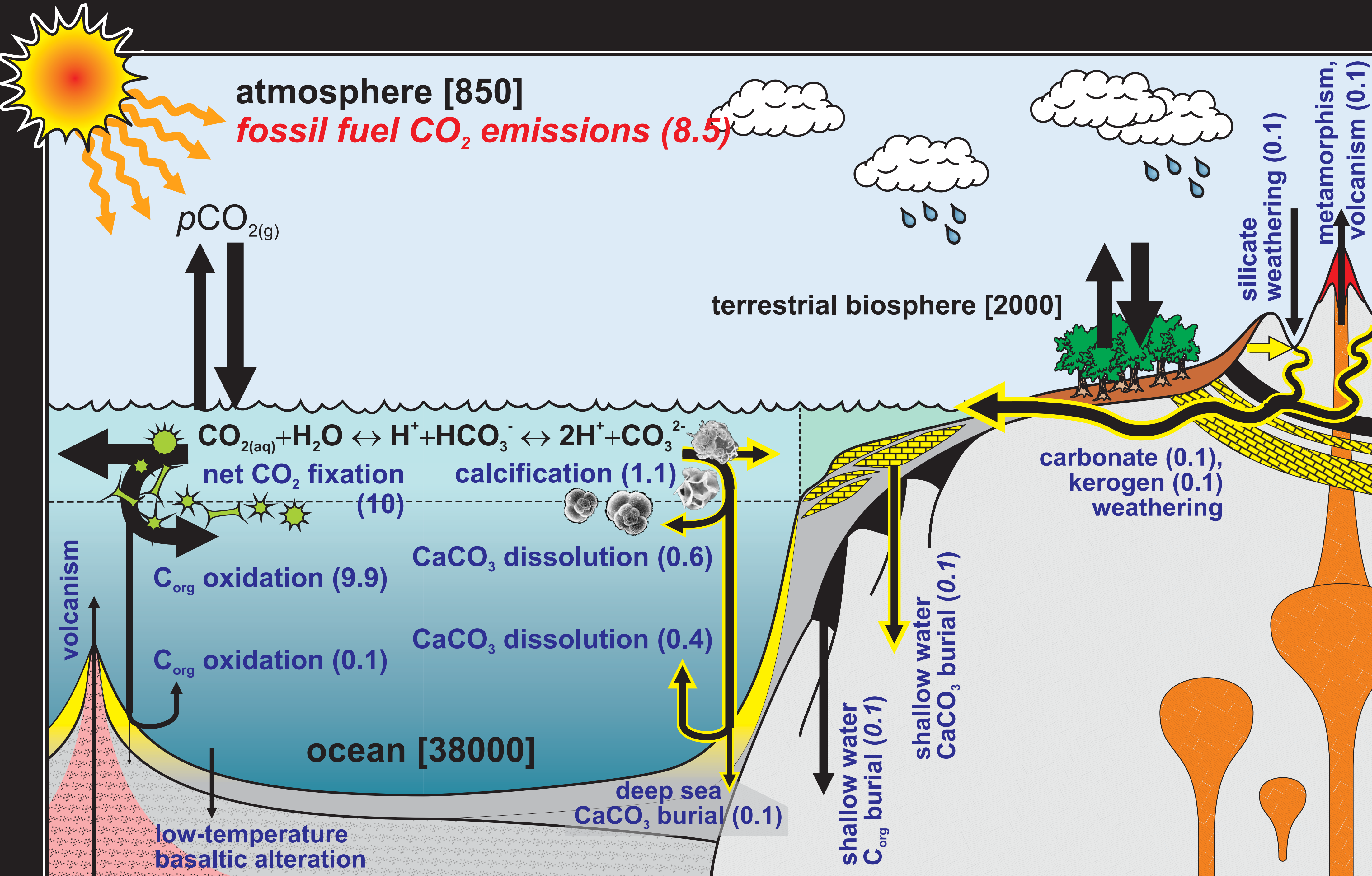
ChrisM, Ashford, England, 2/3/2012 12:07

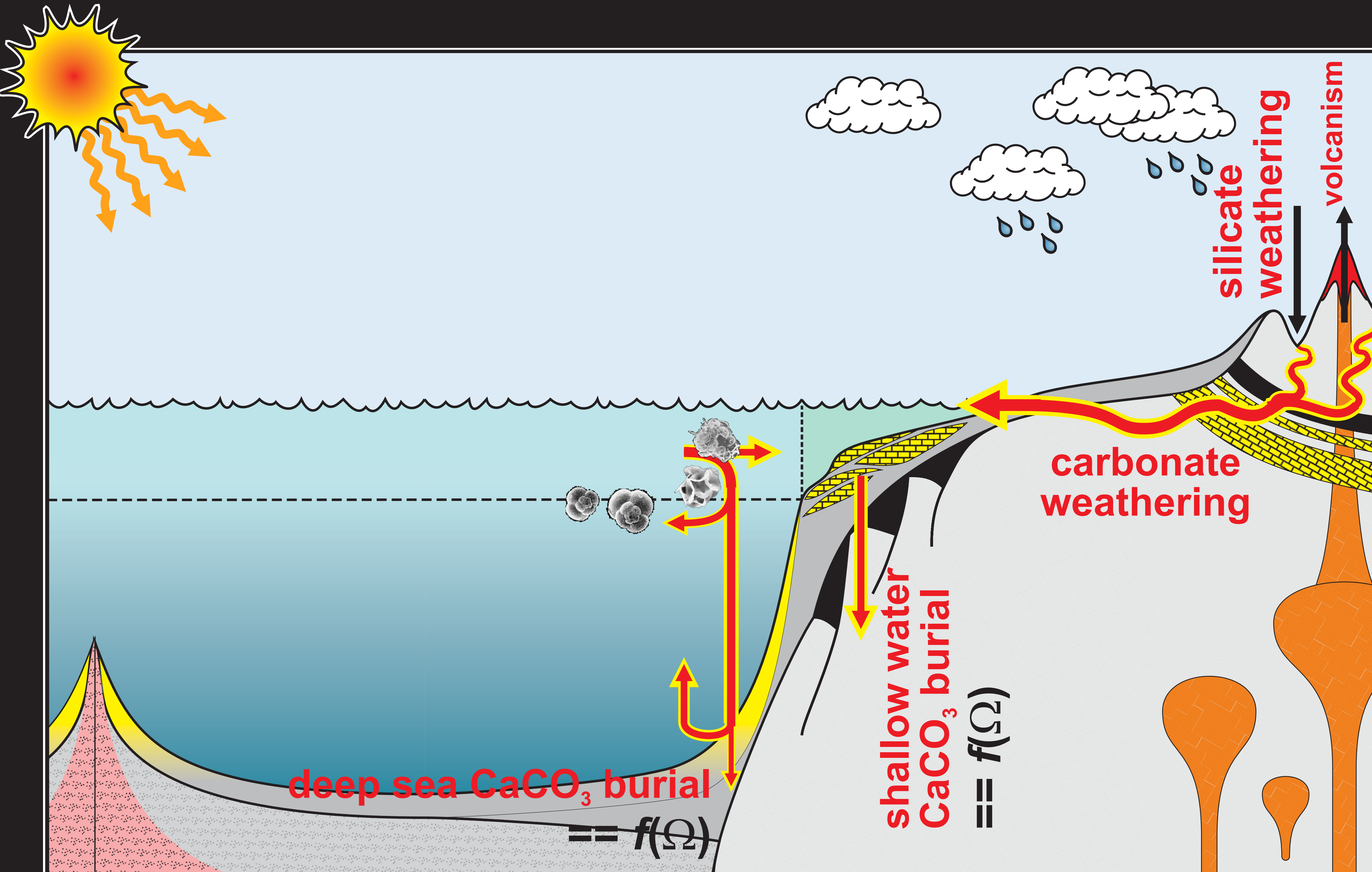
Numerical modelling of The global carbon(ate) cycle

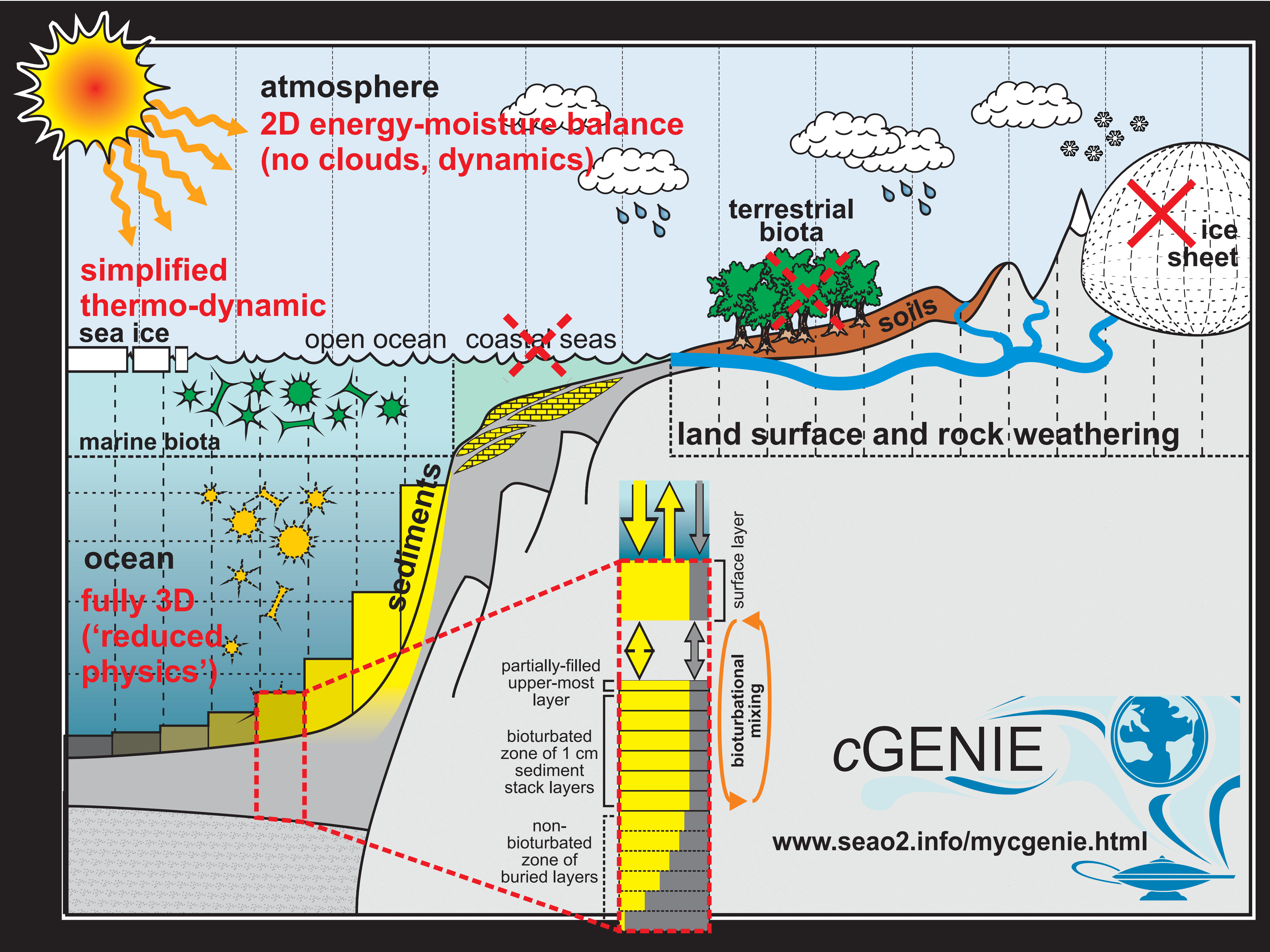
```
! calculate carbonate alkalinity

loc_ALK_DIC = dum_ALK &
& - loc_H4BO4 - loc_OH - loc_HPO4 - 2.0*loc_PO4 - loc_H3SiO4 - loc_NH3 -
loc_HS &
& + loc_H + loc_HSO4 + loc_HF + loc_H3PO4

! estimate the partitioning between the aqueous carbonate species

loc_zed = ( &
&   (4.0*loc_ALK_DIC + dum_DIC*dum_carbconst(icc_k) -
loc_ALK_DIC*dum_carbconst(icc_k))**2 + &
&   4.0*(dum_carbconst(icc_k) - 4.0)*loc_ALK_DIC**2 &
& )**0.5       loc_conc_HCO3 = (dum_DIC*dum_carbconst(icc_k) -
loc_zed)/(dum_carbconst(icc_k) - 4.0)

loc_conc_CO3 = &
& ( &
&   loc_ALK_DIC*dum_carbconst(icc_k) - dum_DIC*dum_carbconst(icc_k) - &
&   4.0*loc_ALK_DIC + loc_zed &
& ) &
& /(2.0*(dum_carbconst(icc_k) - 4.0))

loc_conc_CO2 = dum_DIC - loc_ALK_DIC + &
& ( &
&   loc_ALK_DIC*dum_carbconst(icc_k) - dum_DIC*dum_carbconst(icc_k) - &
&   4.0*loc_ALK_DIC + loc_zed &
& ) &
& /(2.0*(dum_carbconst(icc_k) - 4.0))

loc_H1 = dum_carbconst(icc_k1)*loc_conc_CO2/loc_conc_HCO3

loc_H2 = dum_carbconst(icc_k2)*loc_conc_HCO3/loc_conc_CO3
```

The global carbon cycle

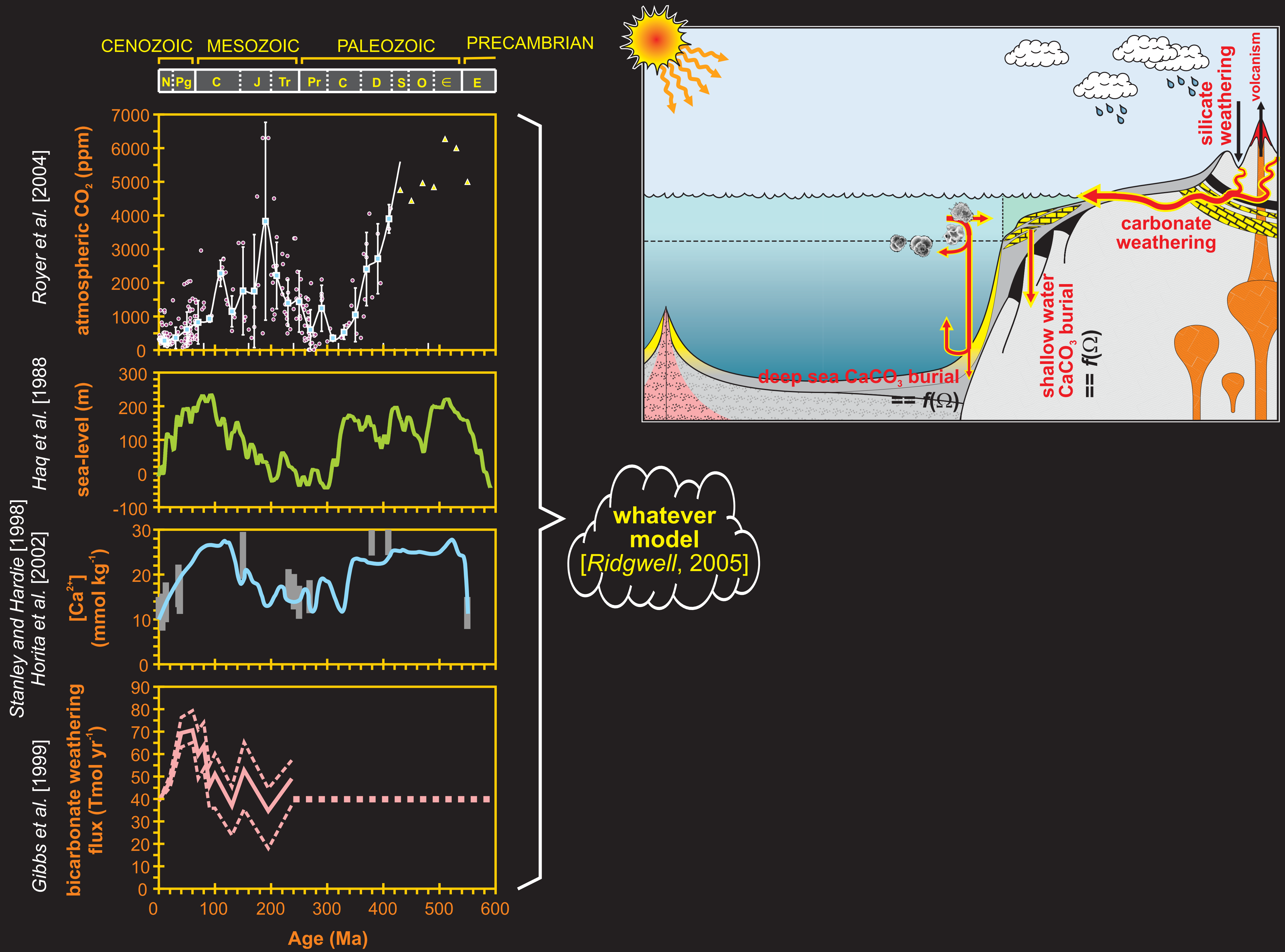


The global carbon(ate) cycle: Control of saturation (and CO_3^{2-})

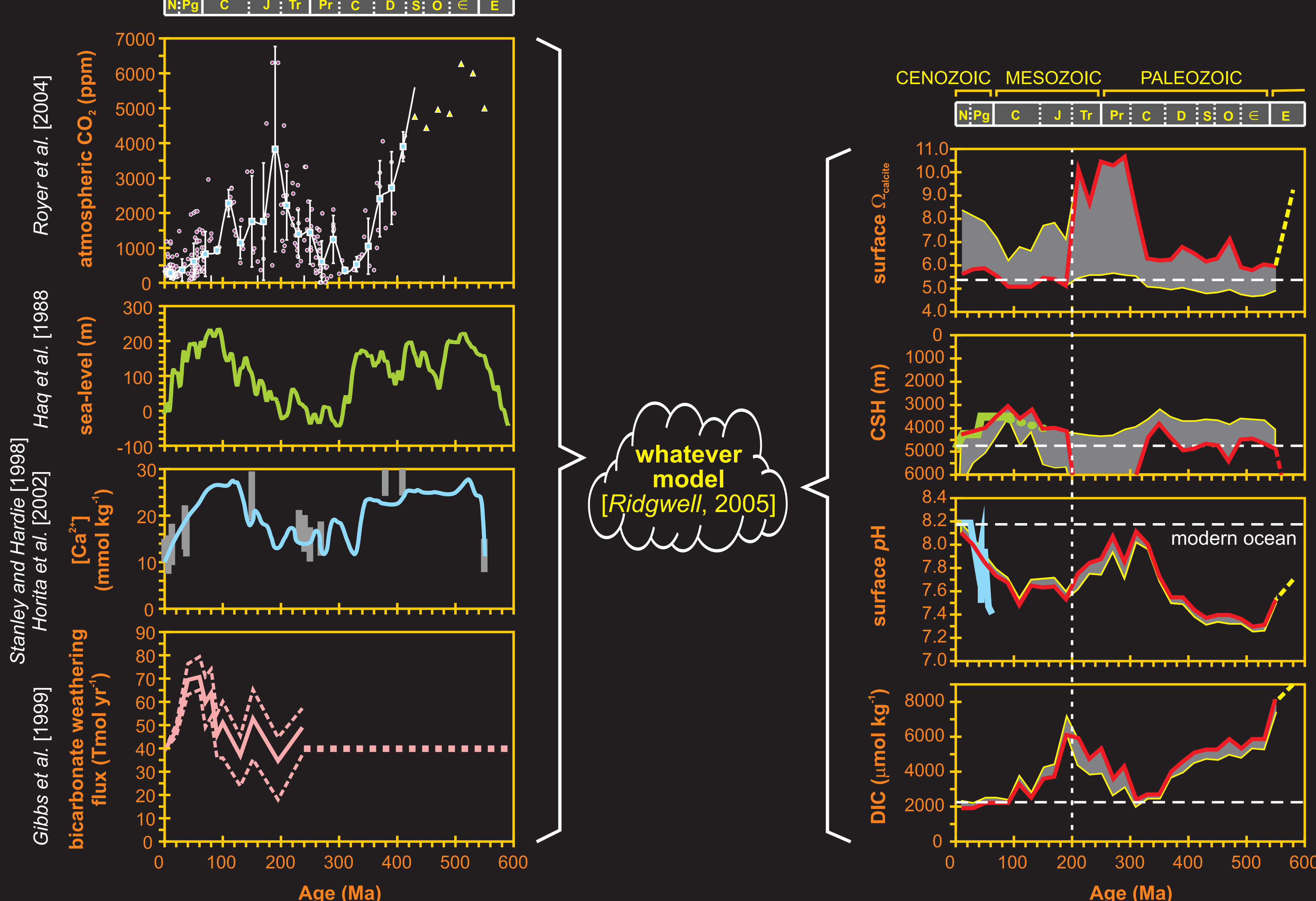




atmosphere
2D energy-moisture balance
(no clouds, dynamics)
simplified
thermo-dynamic
sea ice
open ocean
coastal seas
terrestrial
biota
soils
ice
sheet
marine biota
land surface and rock weathering
ocean
fully 3D
('reduced
physics')
sediments
surface layer
partially-filled
upper-most
layer
bioturbated
zone of 1 cm
sediment
stack layers
bioturbational
mixing
non-
bioturbated
zone of
buried layers
cGENIE
www.seao2.info/mycgenie.html


CENOZOIC
MESOZOIC
PALEOZOIC
PRECAMBRIAN
N
Pg
C
J
Tr
Pr
C
D
S
O
∈
E
Royer et al. [2004]
atmospheric CO_2 (ppm)
Haq et al. [1988
sea-level (m)
Stanley and Hardie [1998]
Horita et al. [2002]
$[Ca^{2+}]$ (mmol kg^{-1})
Gibbs et al. [1999]
bicarbonate weathering flux (Tmol yr^{-1})
Age (Ma)
whatever model [Ridgwell, 2005]
volcanism
silicate weathering
carbonate weathering
shallow water $CaCO_3$ burial
== $f(\Omega)$
deep sea $CaCO_3$ burial
== $f(\Omega)$

Model projections



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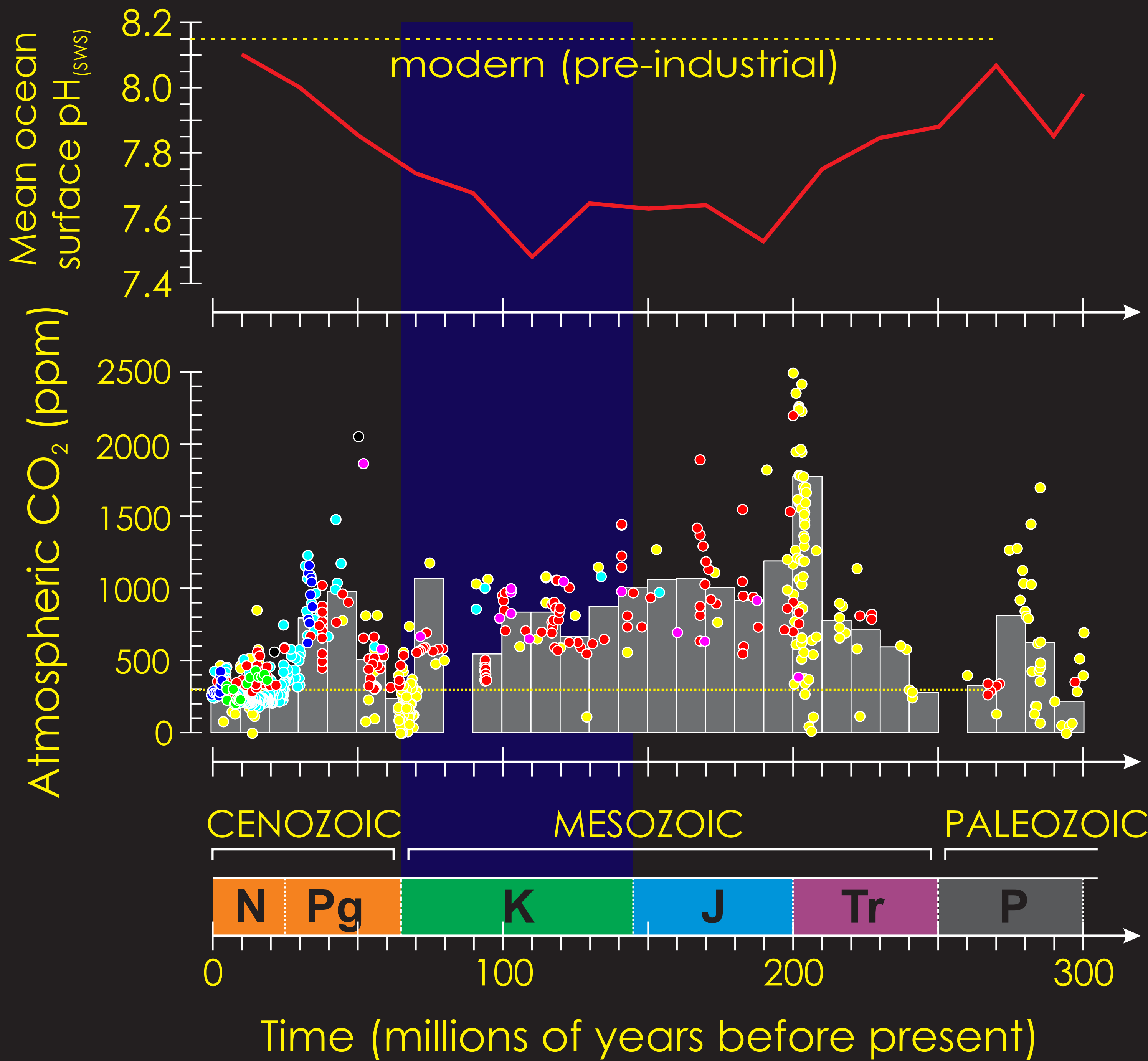

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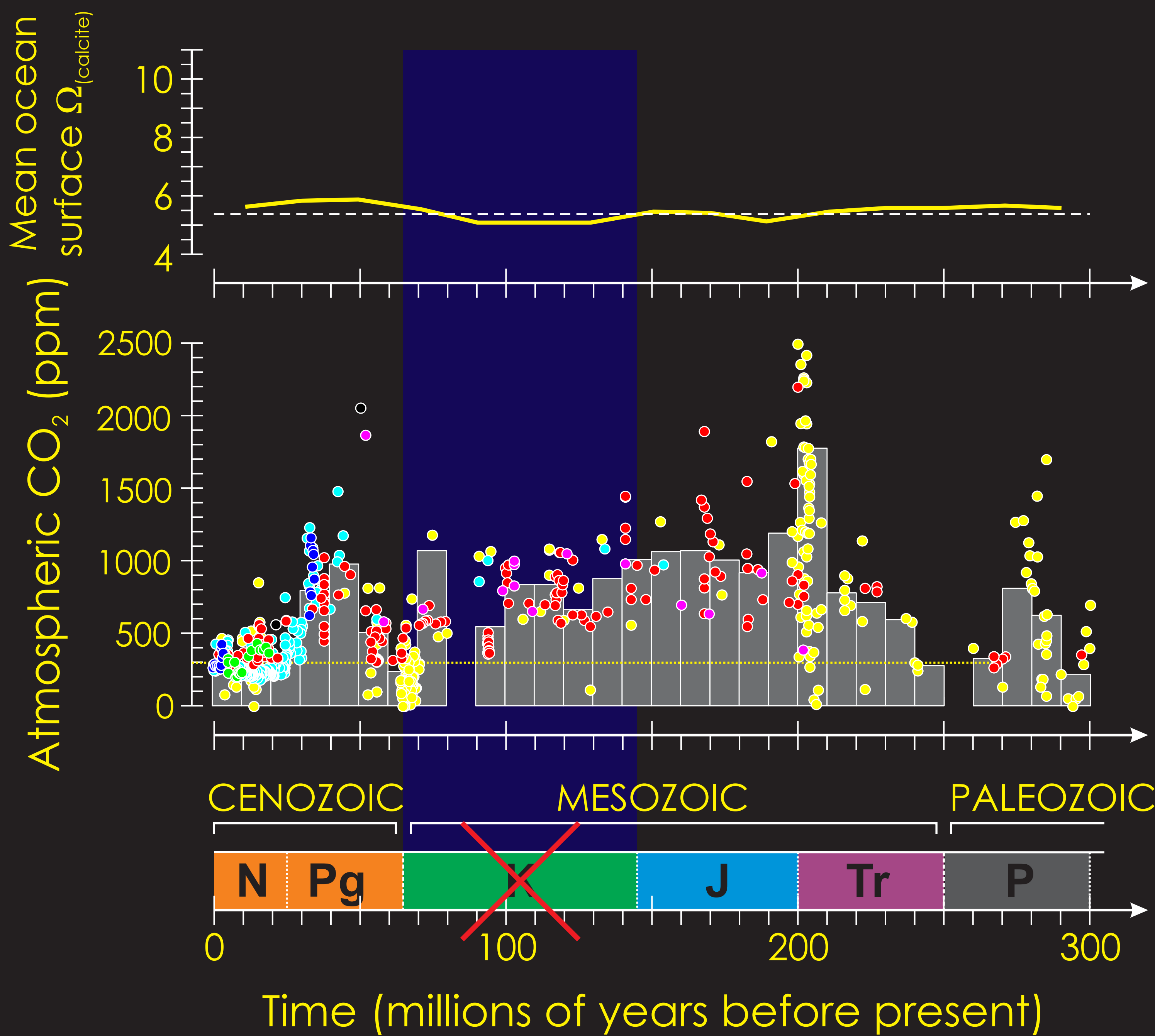
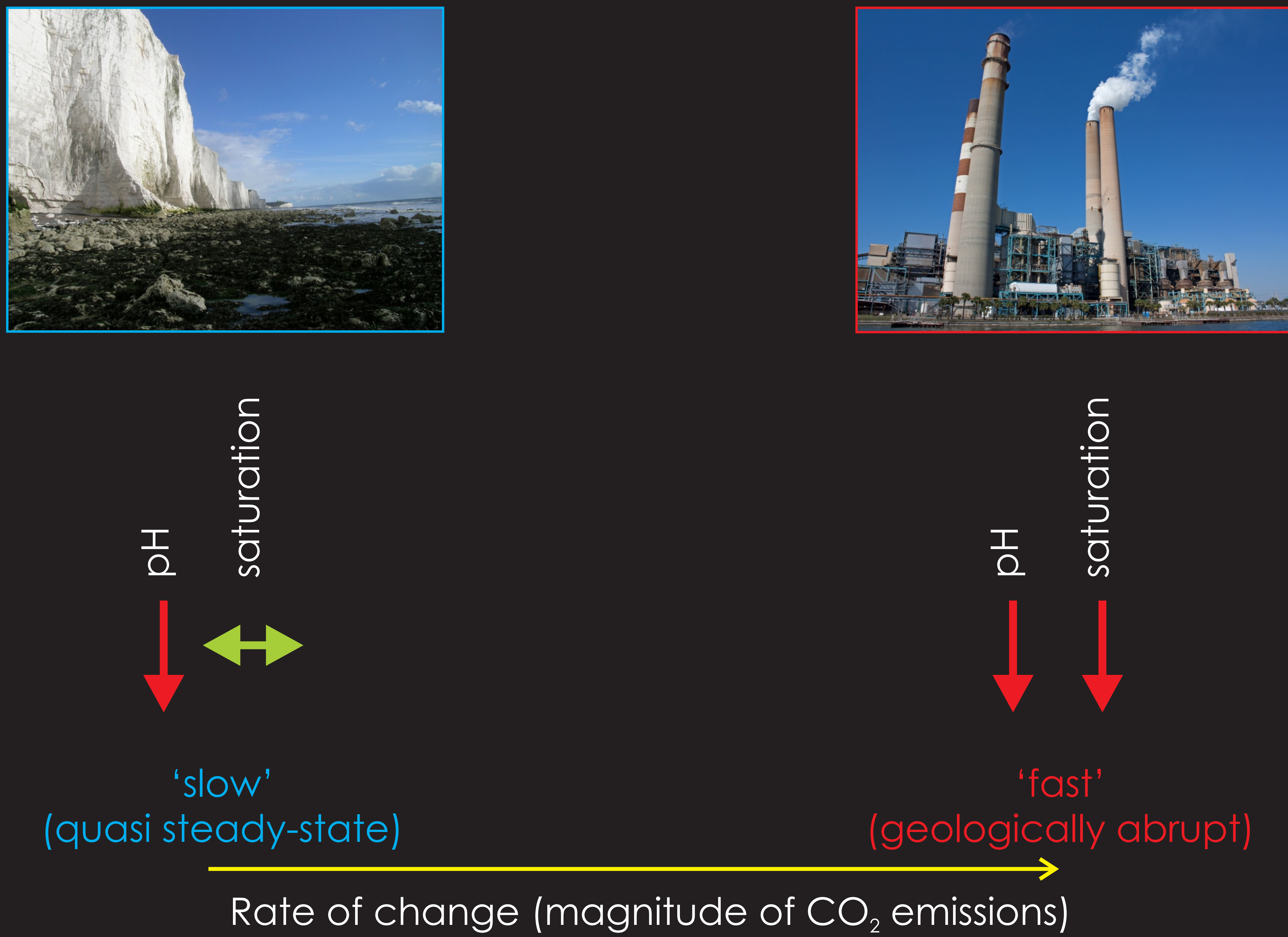




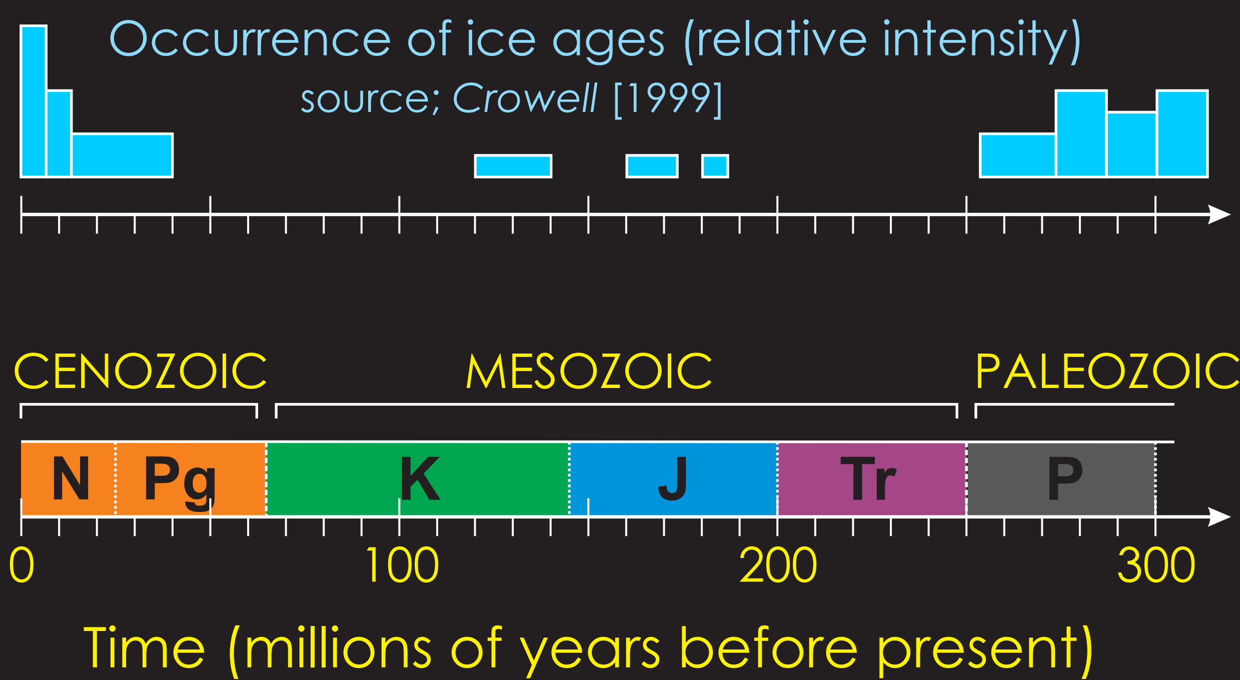
pH
saturation
pH
saturation
'slow'
(quasi steady-state)
'fast'
(geologically abrupt)
Rate of change (magnitude of CO_2 emissions)

Is there a past 'analogue' for the future consequences of massive CO_2 release and ocean acidification?

More complete geological record (more rock!)
(more and better preserved and constrained proxies)

←

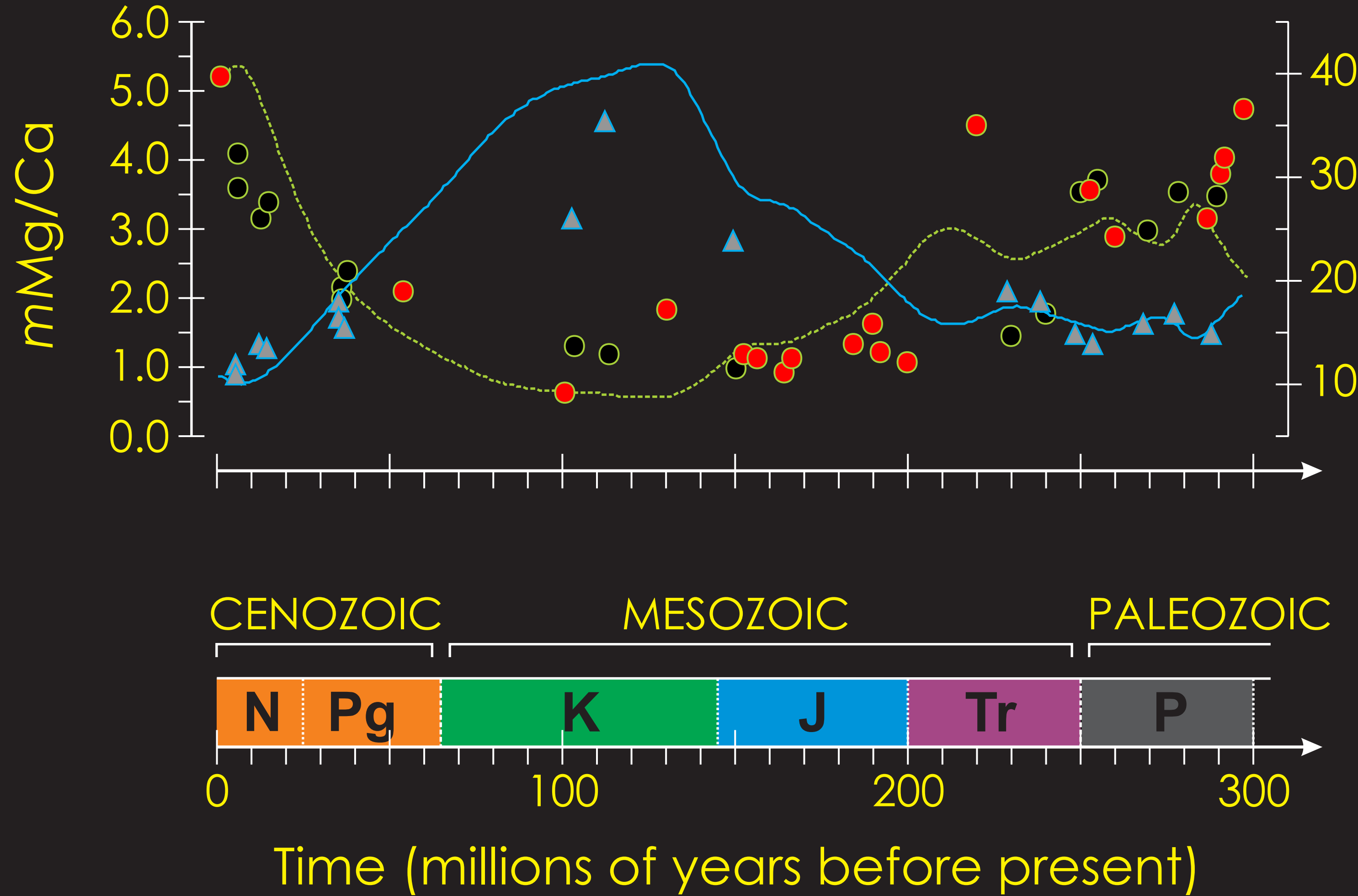
← More similar (cooler) climate →
More similar (lower) sealevel

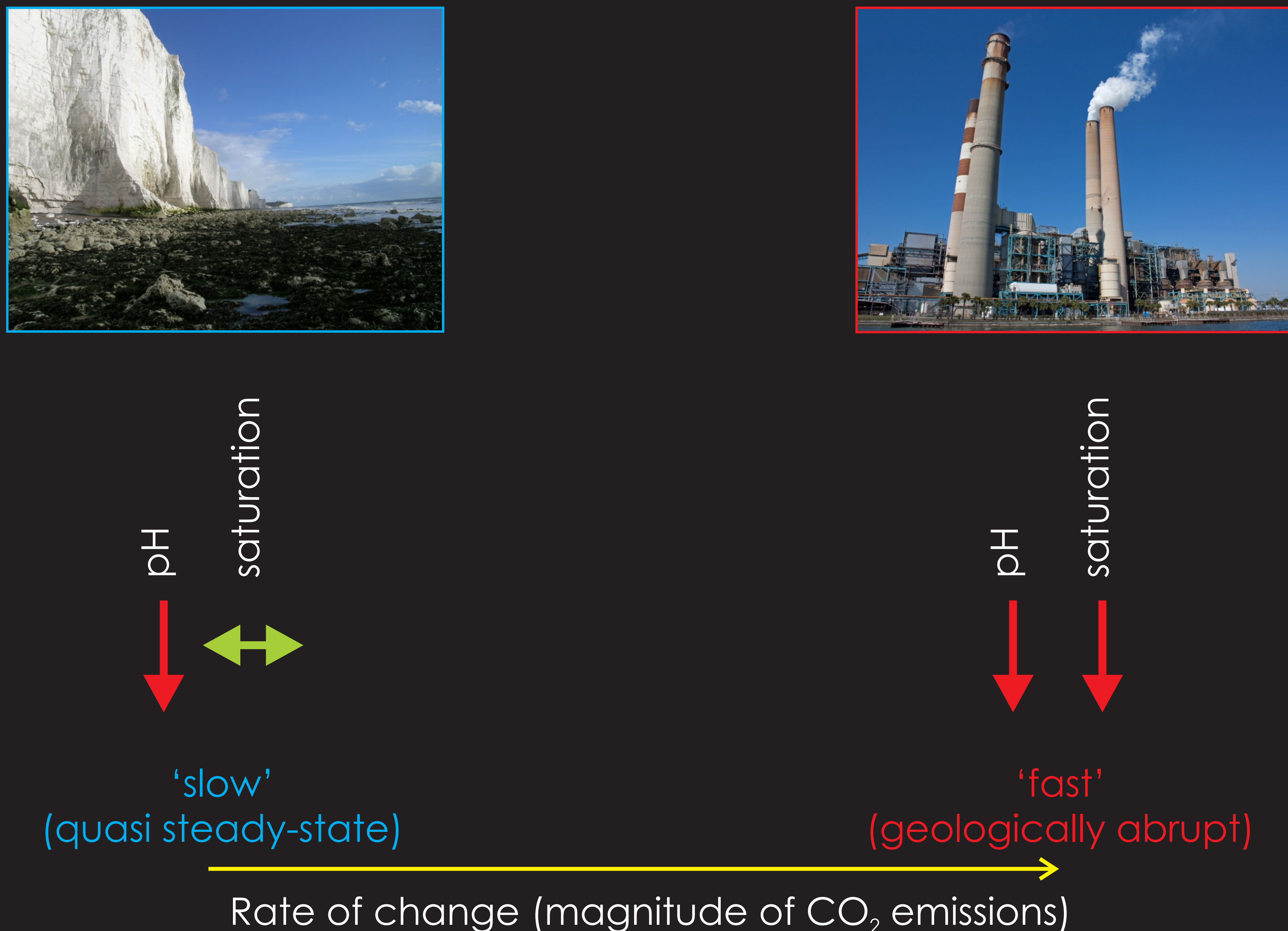


Is there a past 'analogue' for the future consequences of massive CO_2 release and ocean acidification?

('aragonite' vs. 'calcite' as the dominant reef mineralogy)

More similar cation chemistry




pH
saturation
pH
saturation
'slow'
(quasi steady-state)
'fast'
(geologically abrupt)
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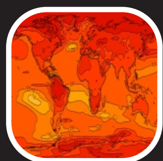
The geological record app store

✓  Massive CO_2 release

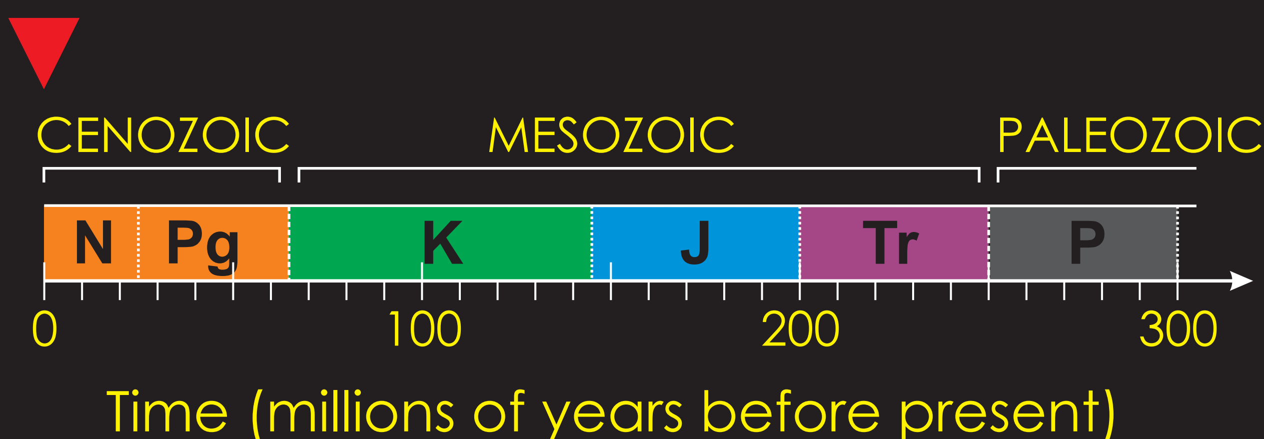
✓  Increasing atmospheric pCO_2

✓  Warming

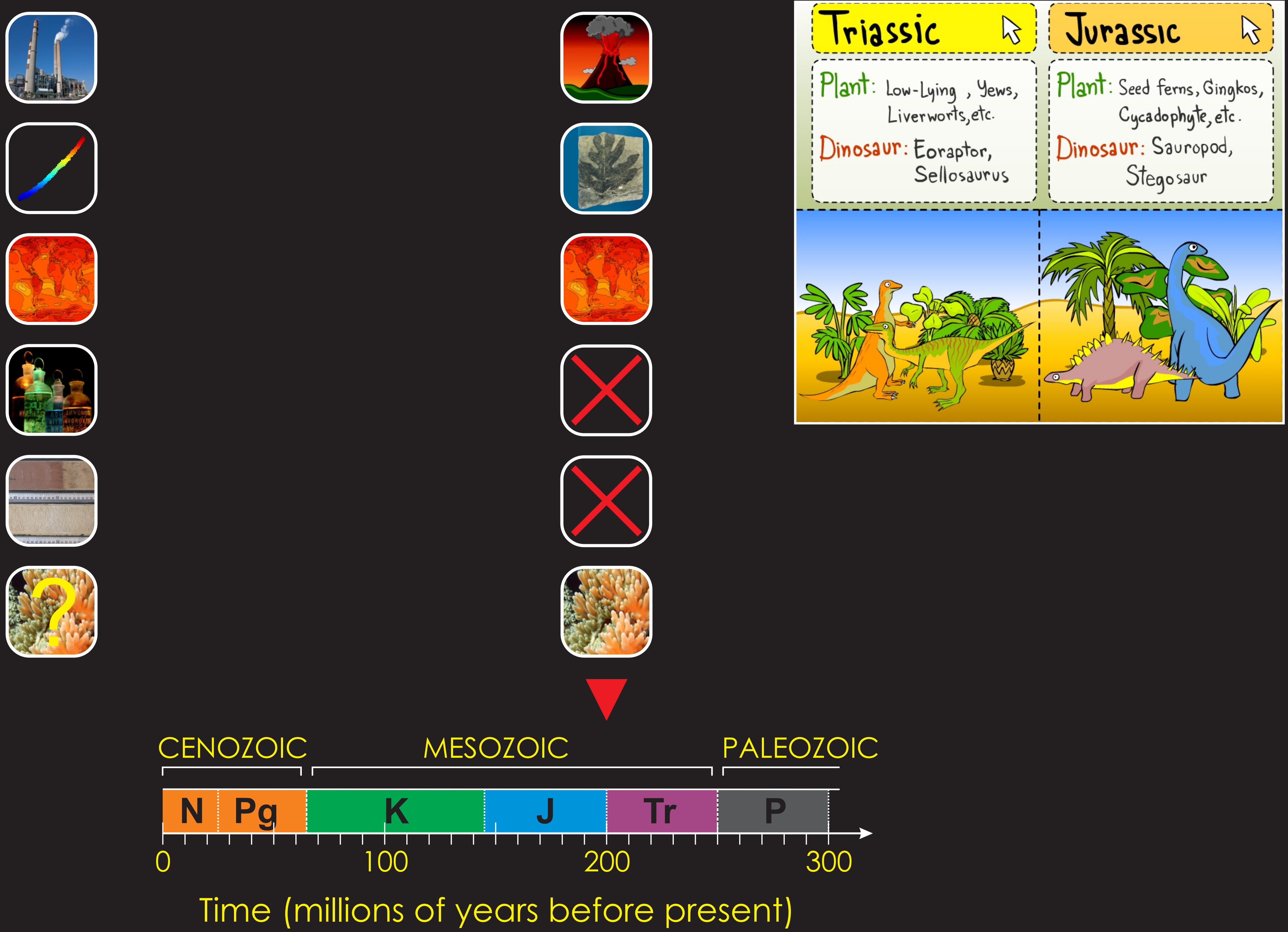
✓  **pH decline**

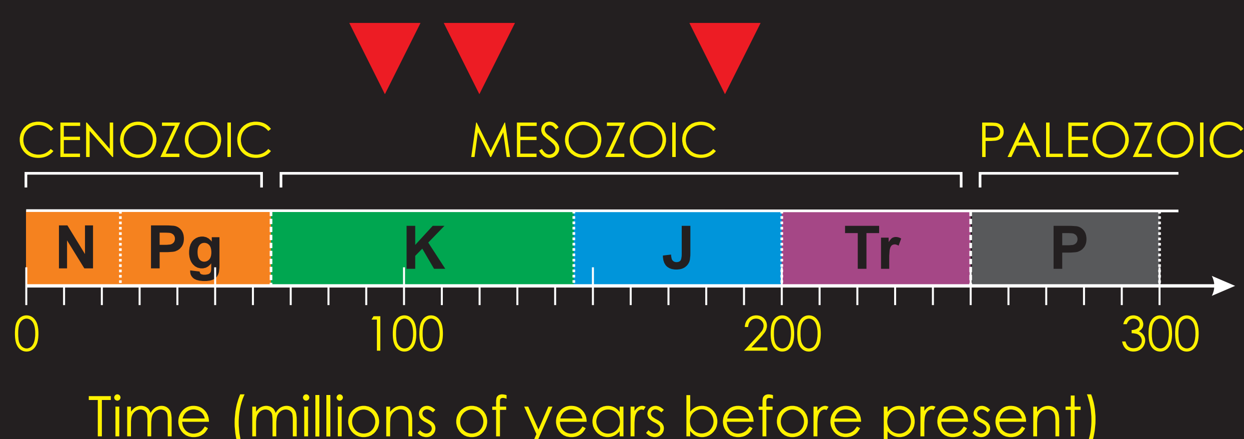
✓  **Carbonate saturation decline**

?  Biotic/ecosystem response?




CENOZOIC
MESOZOIC
PALEOZOIC
N
Pg
K
J
Tr
P
0
100
200
300
Time (millions of years before present)
SCIENCEphotoLIBRARY


Triassic
Plant: Low-Lying, Yews, Liverworts, etc.
Dinosaur: Eoraptor, Sellosaurus
Jurassic
Plant: Seed ferns, Gingkos, Cycadophyte, etc.
Dinosaur: Sauropod, Stegosaur
CENOZOIC
MESOZOIC
PALEOZOIC
N
Pg
K
J
Tr
P
0
100
200
300
Time (millions of years before present)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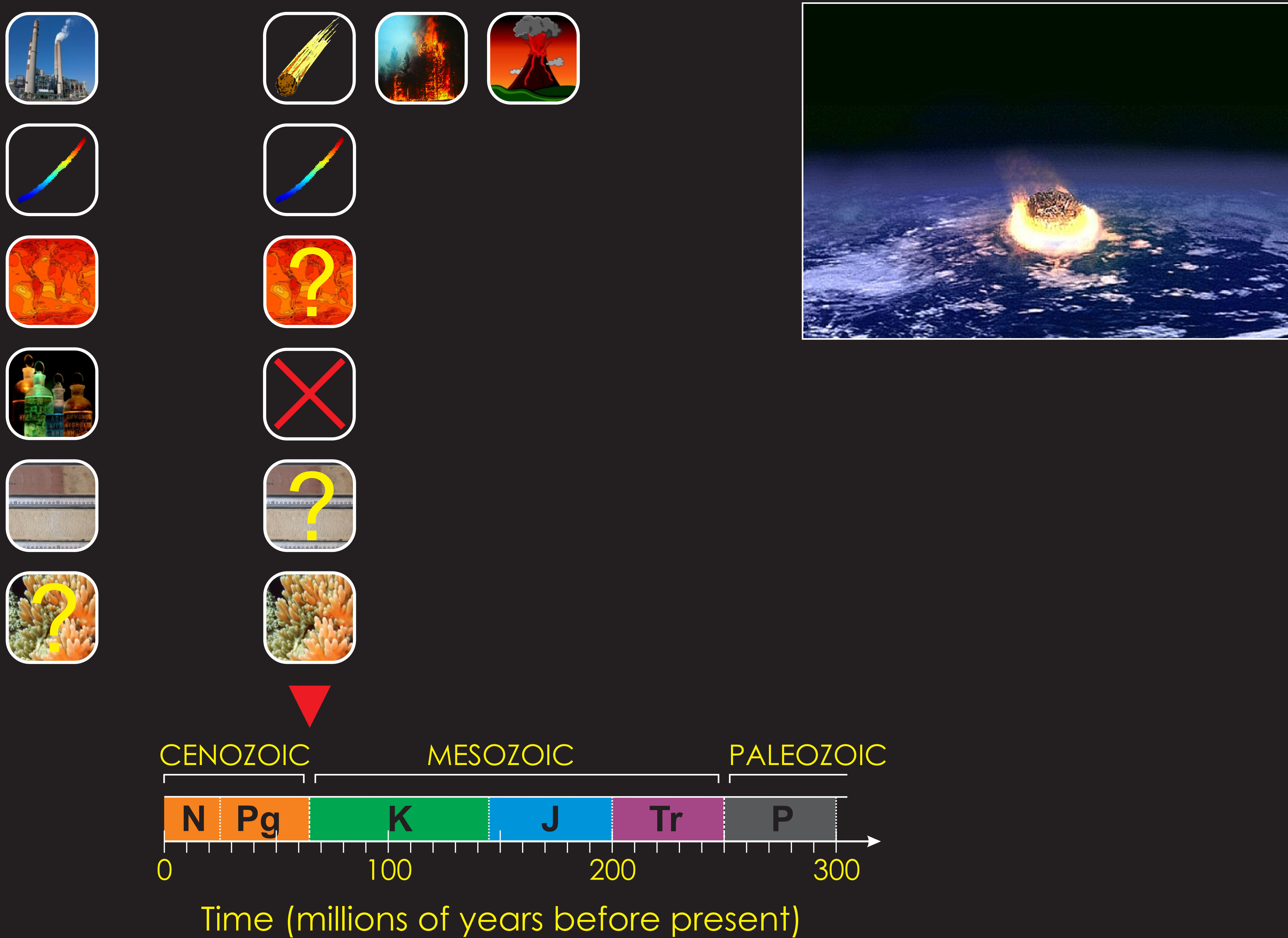
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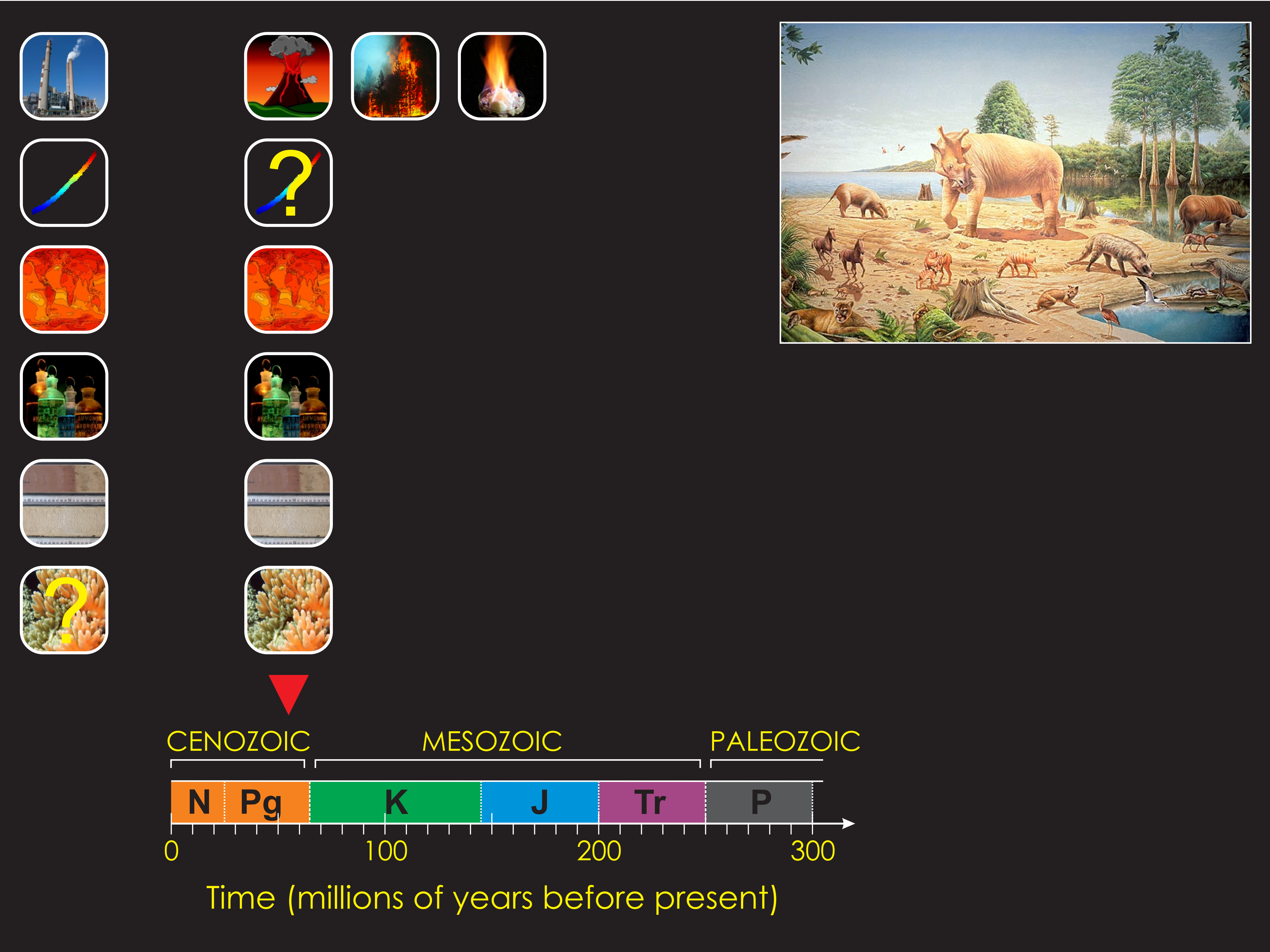
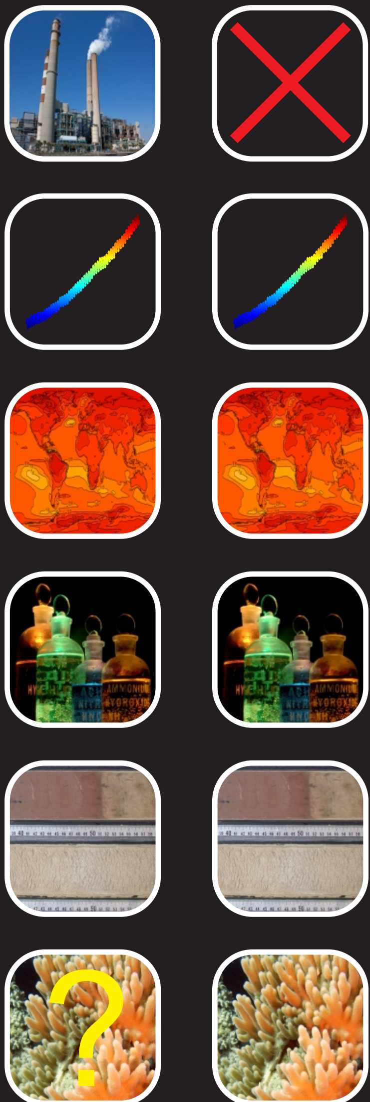
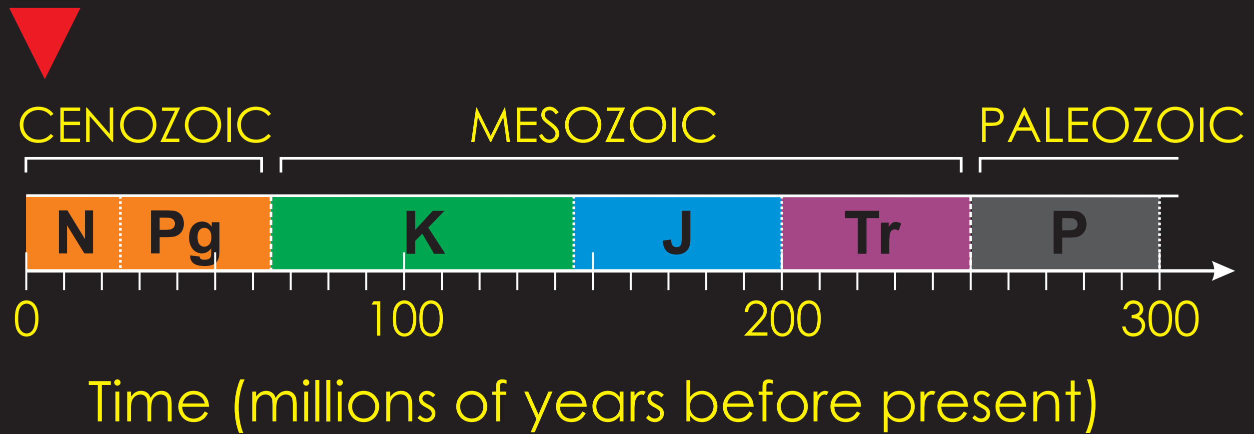
300
Time (millions of years before present)


CENOZOIC
MESOZOIC
PALEOZOIC
N
Pg
K
J
Tr
P
0
100
200
300
Time (millions of years before present)

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MESOZOIC
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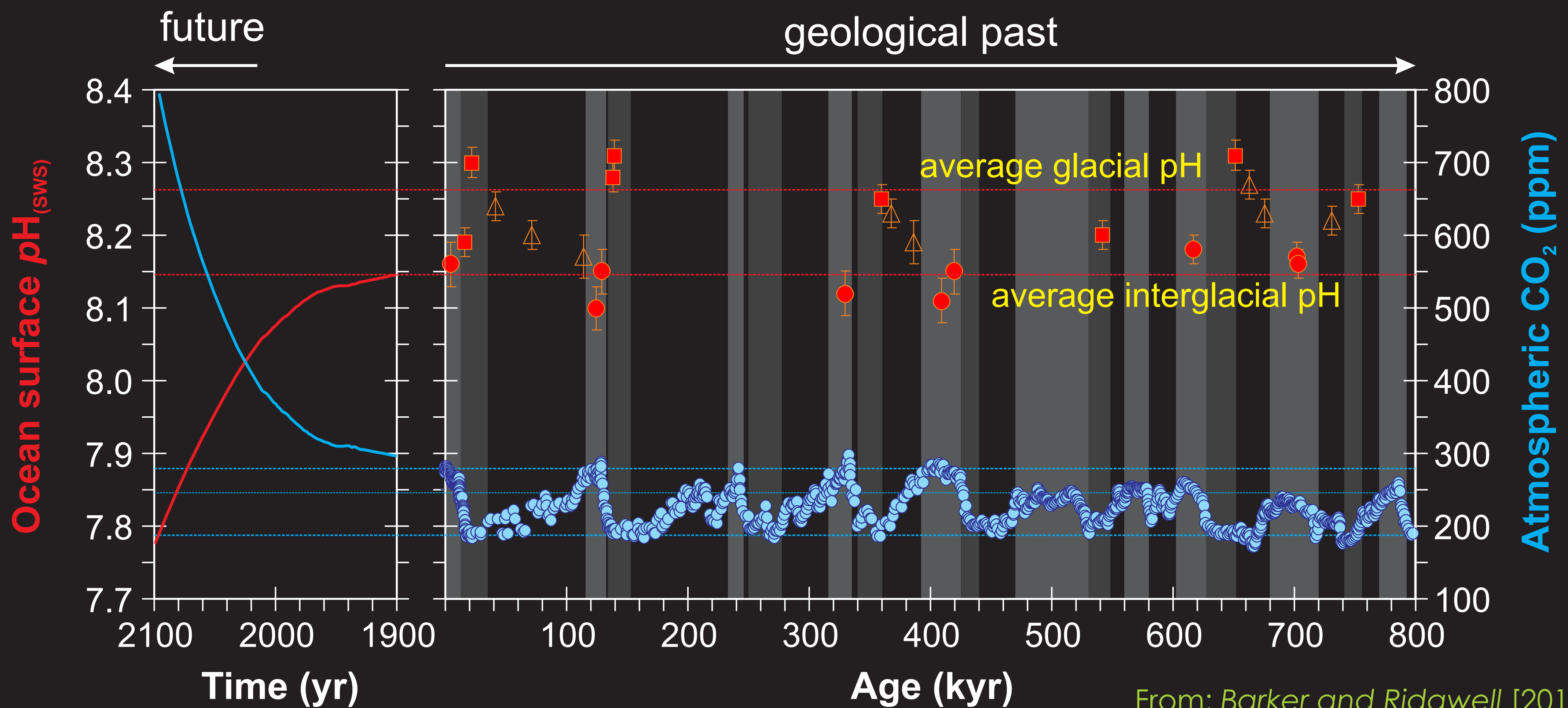
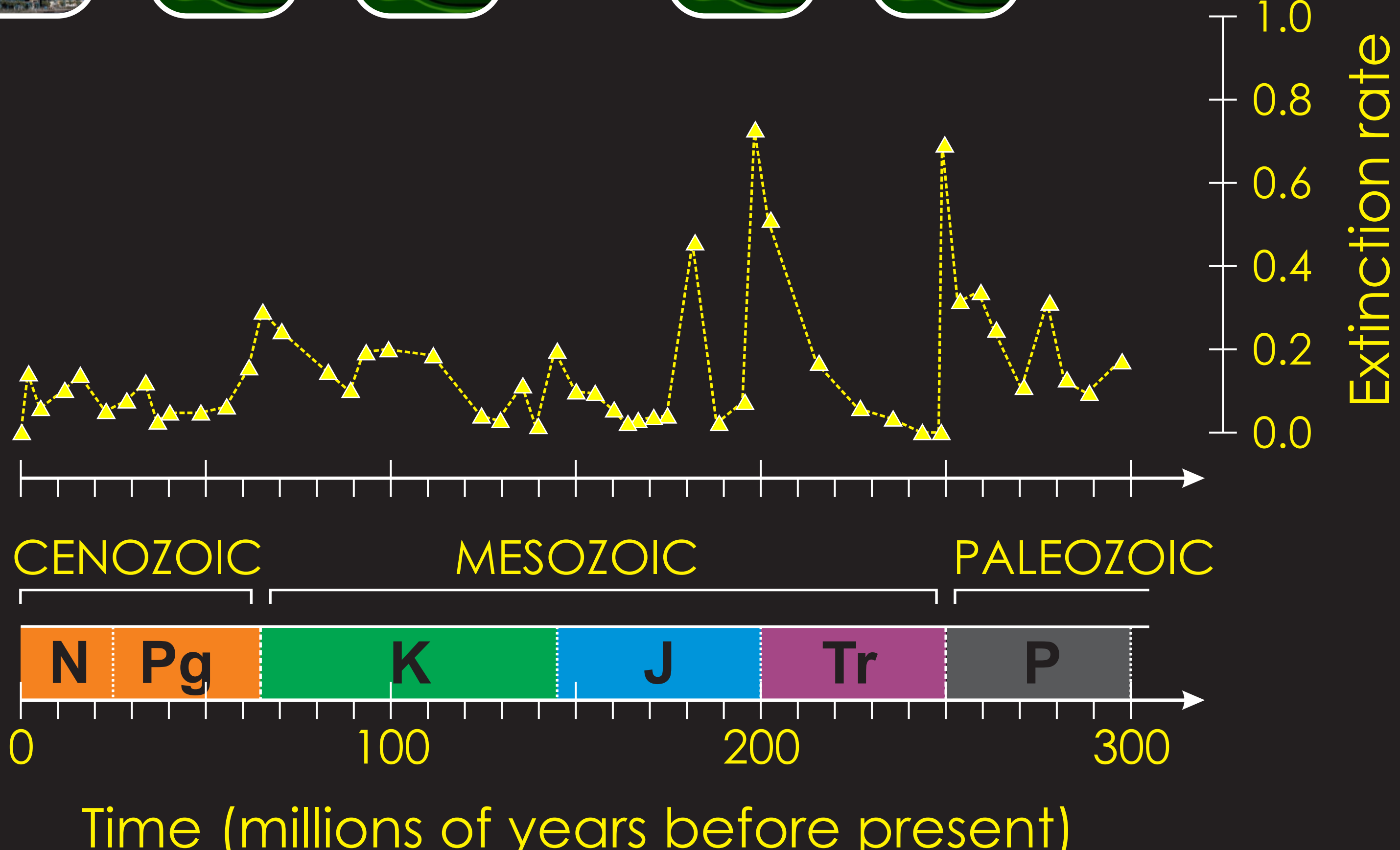
Time (millions of years before present)



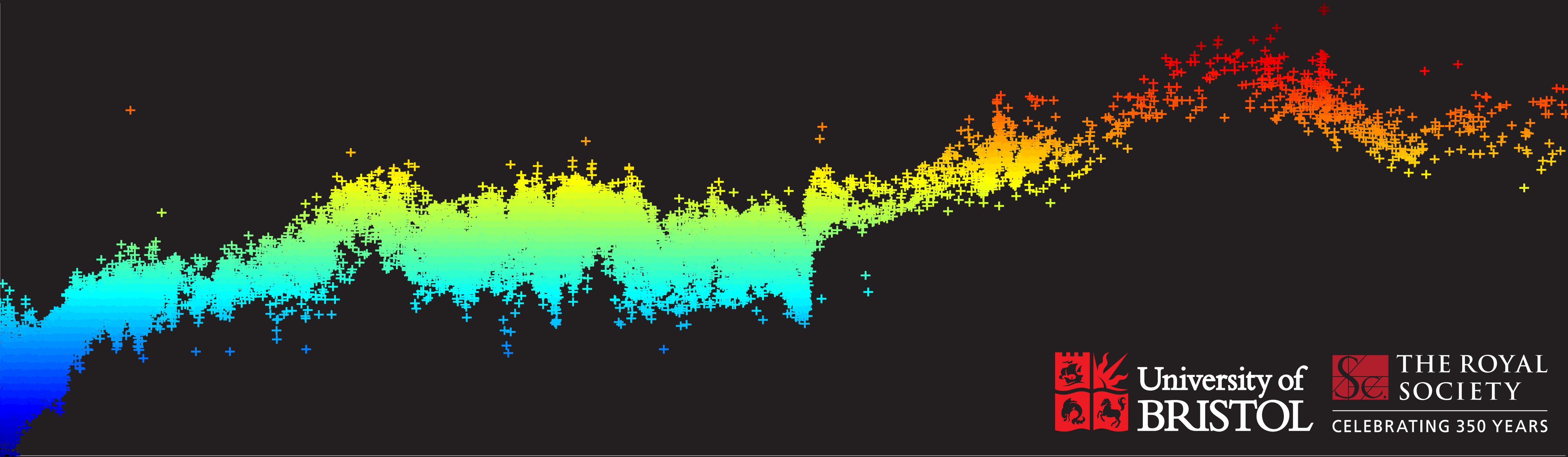
From: *Barker and Ridgwell* [2012]

Past potential ocean acidification analogues are characterized by
reduced pH and saturation state
(likely requiring massive and rapid CO_2 release)

Numerical models can help 'fill in the gaps' by combining 2nd order proxy information to derive 1st order constraints

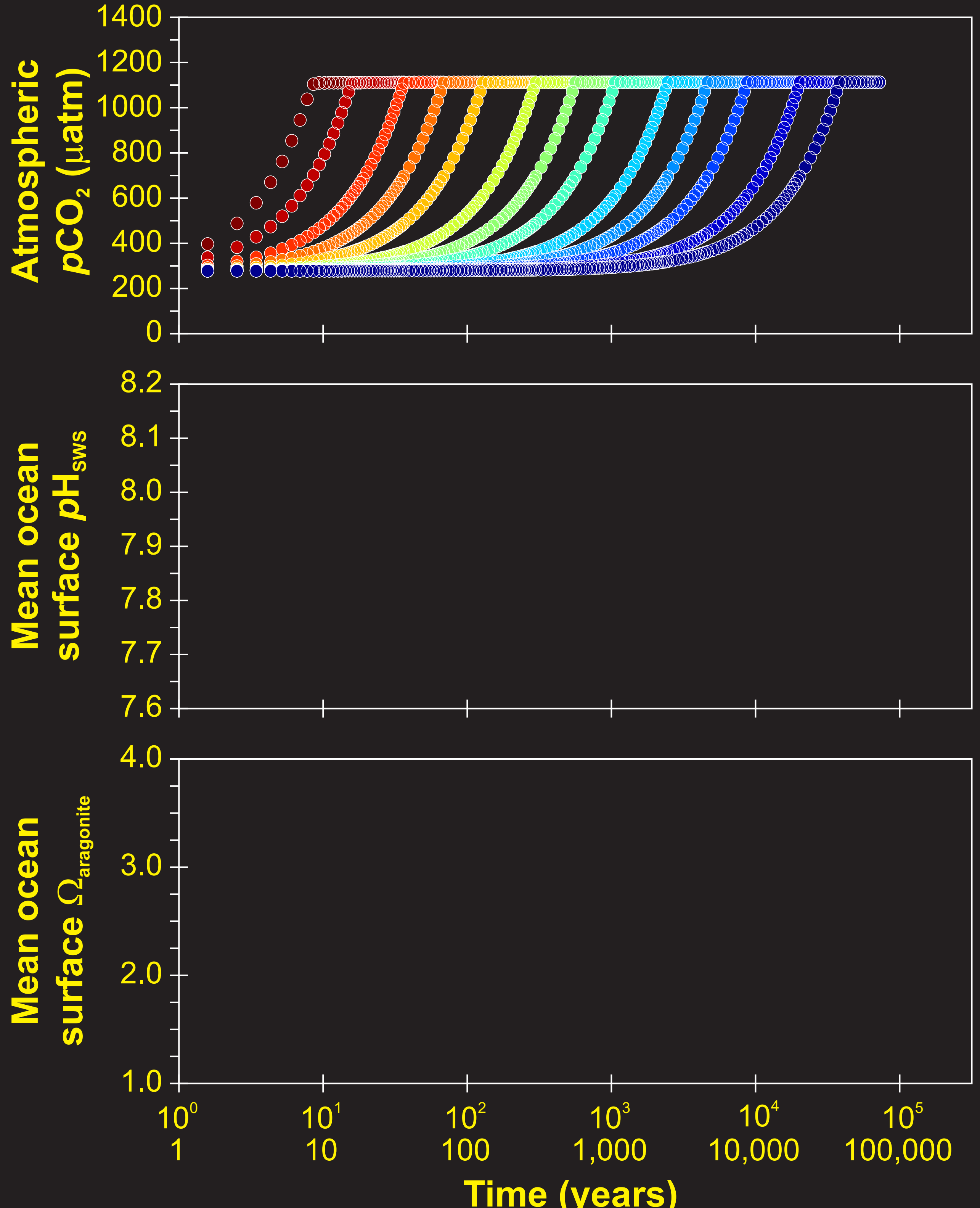


Bärbel Hönisch, Daniela N. Schmidt, Ellen Thomas, Samantha J. Gibbs, Appy Sluijs, Lee Kump, Richard Zeebe, Rowan Martindale, Sarah E. Greene, Wolfgang Kiessling, Justin Ries, Jim Zachos, Dana L. Royer, Stephen Barker, Thomas M. Marchitto Jr., Ryan Moyer, Carles Pelejero, Branwen Williams, Patrizia Ziveri, Gavin L. Foster, Branwen Williams

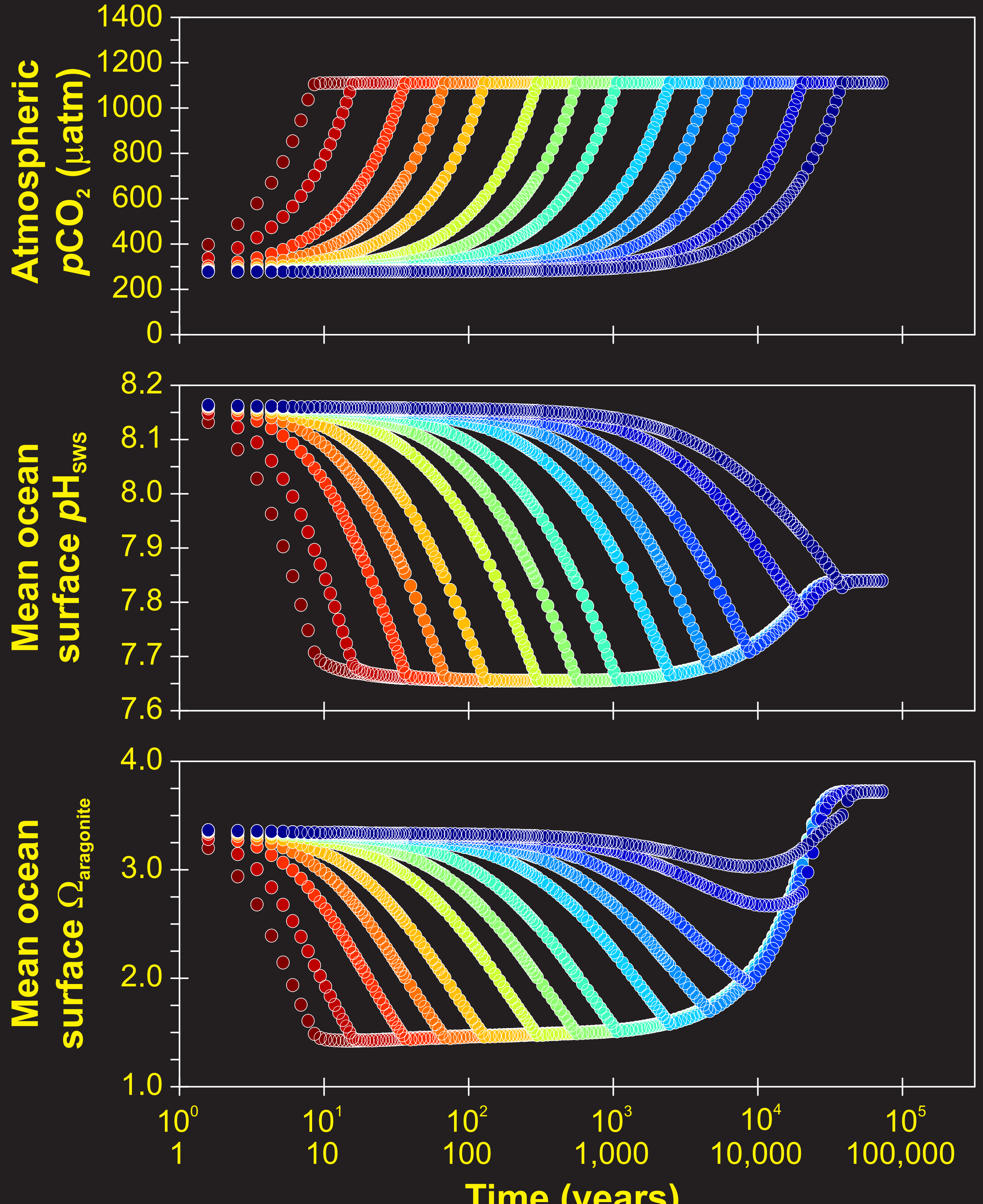


University of BRISTOL

THE ROYAL SOCIETY
CELEBRATING 350 YEARS

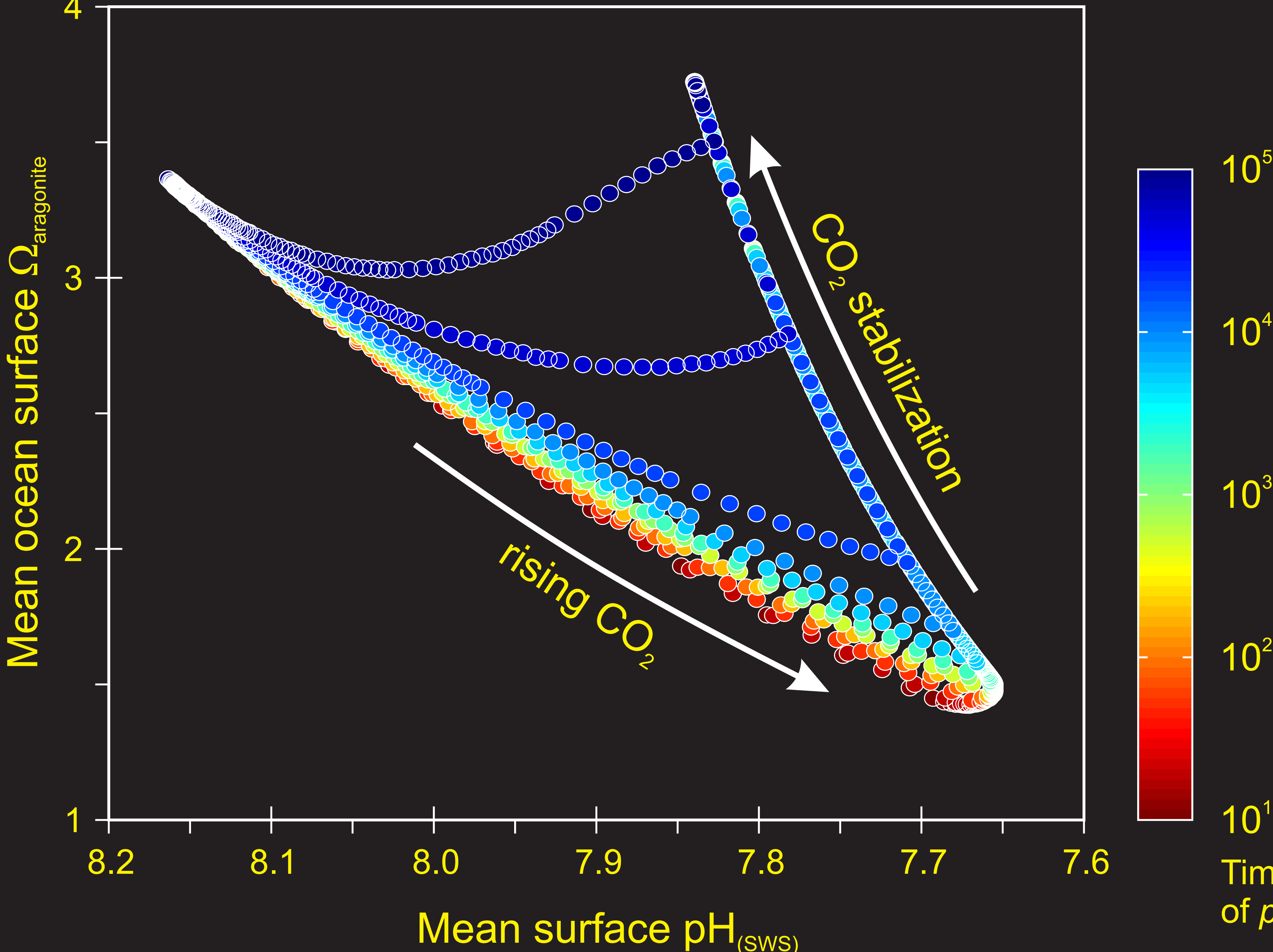


From: *Hönisch et al.* [2012]



From: *Hönisch et al.* [2012]

Time-scale dependence of the nature of ocean carbonate chemistry changes



From: *Hönisch et al.* [2012]