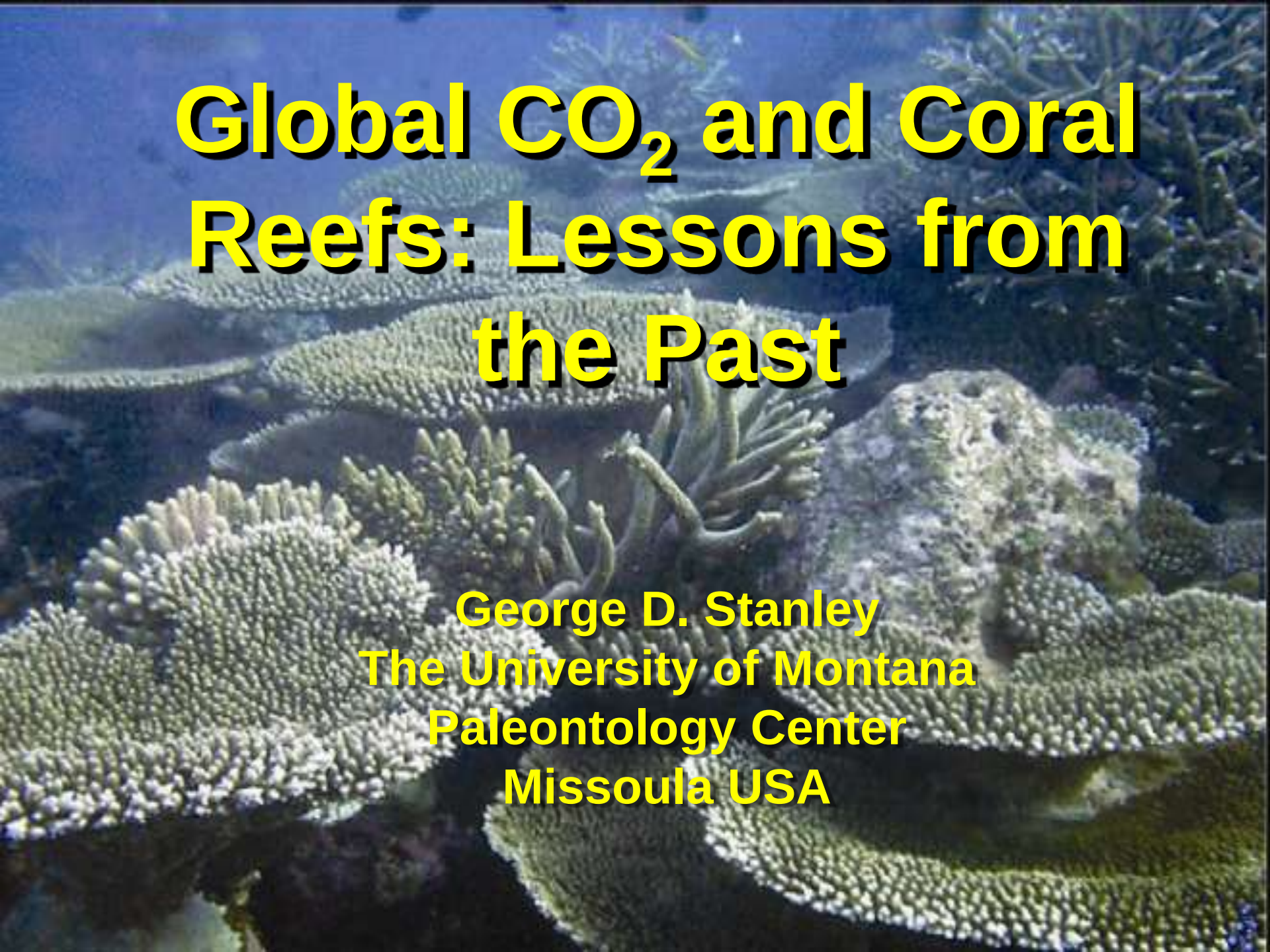
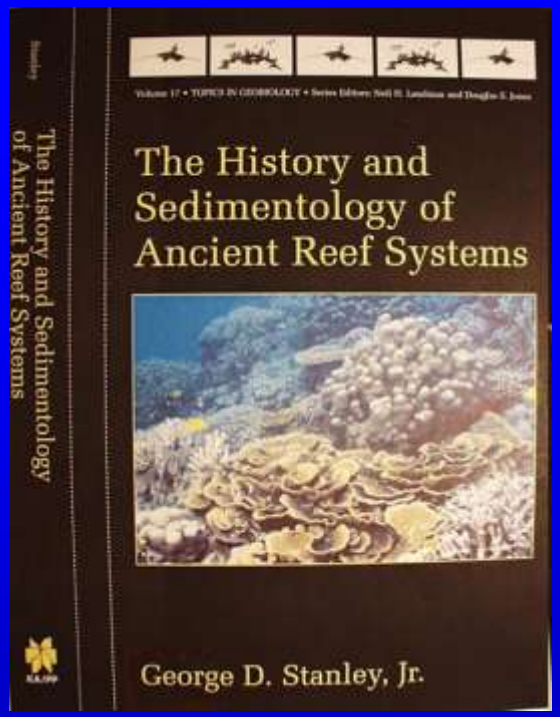
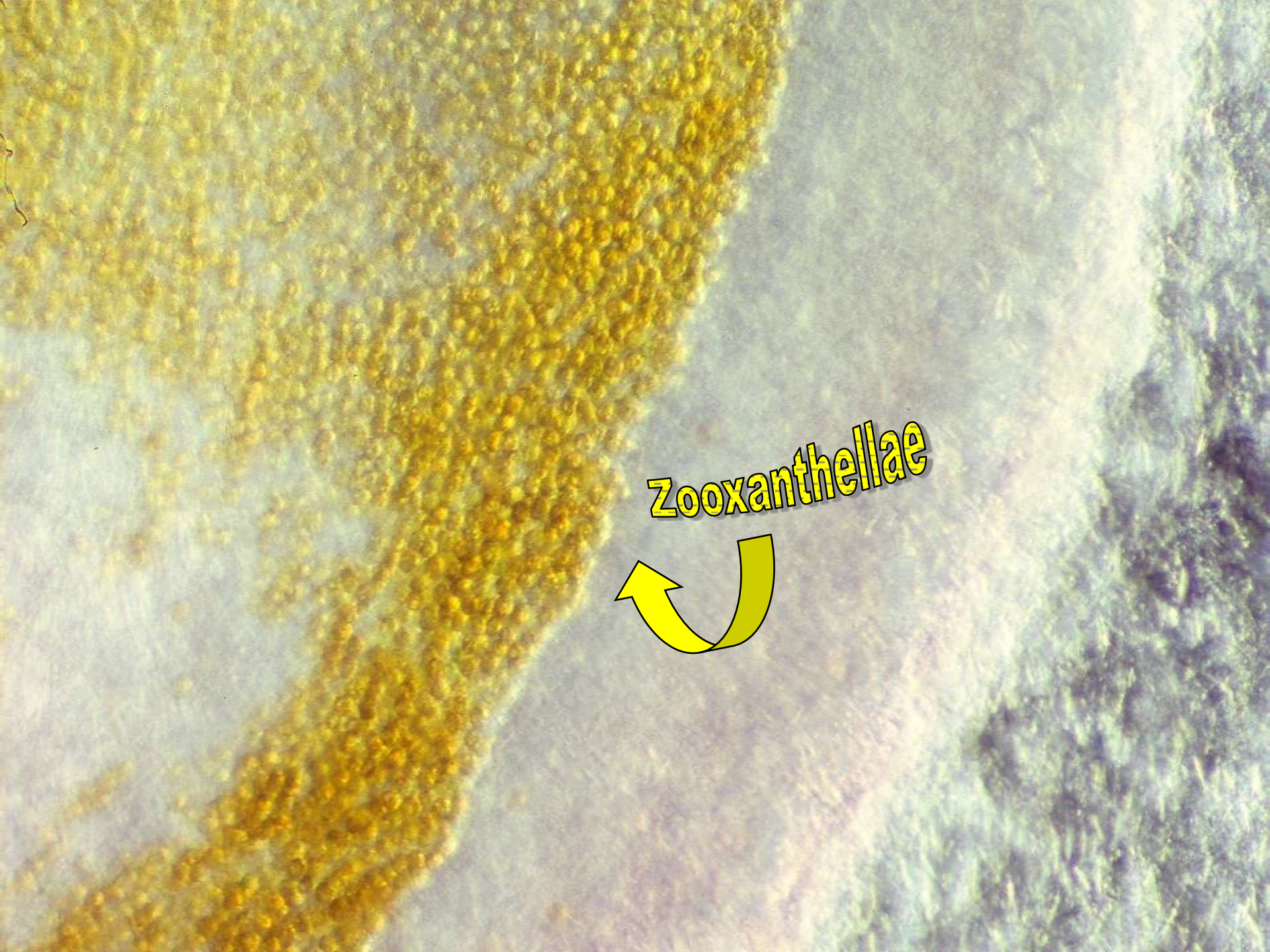


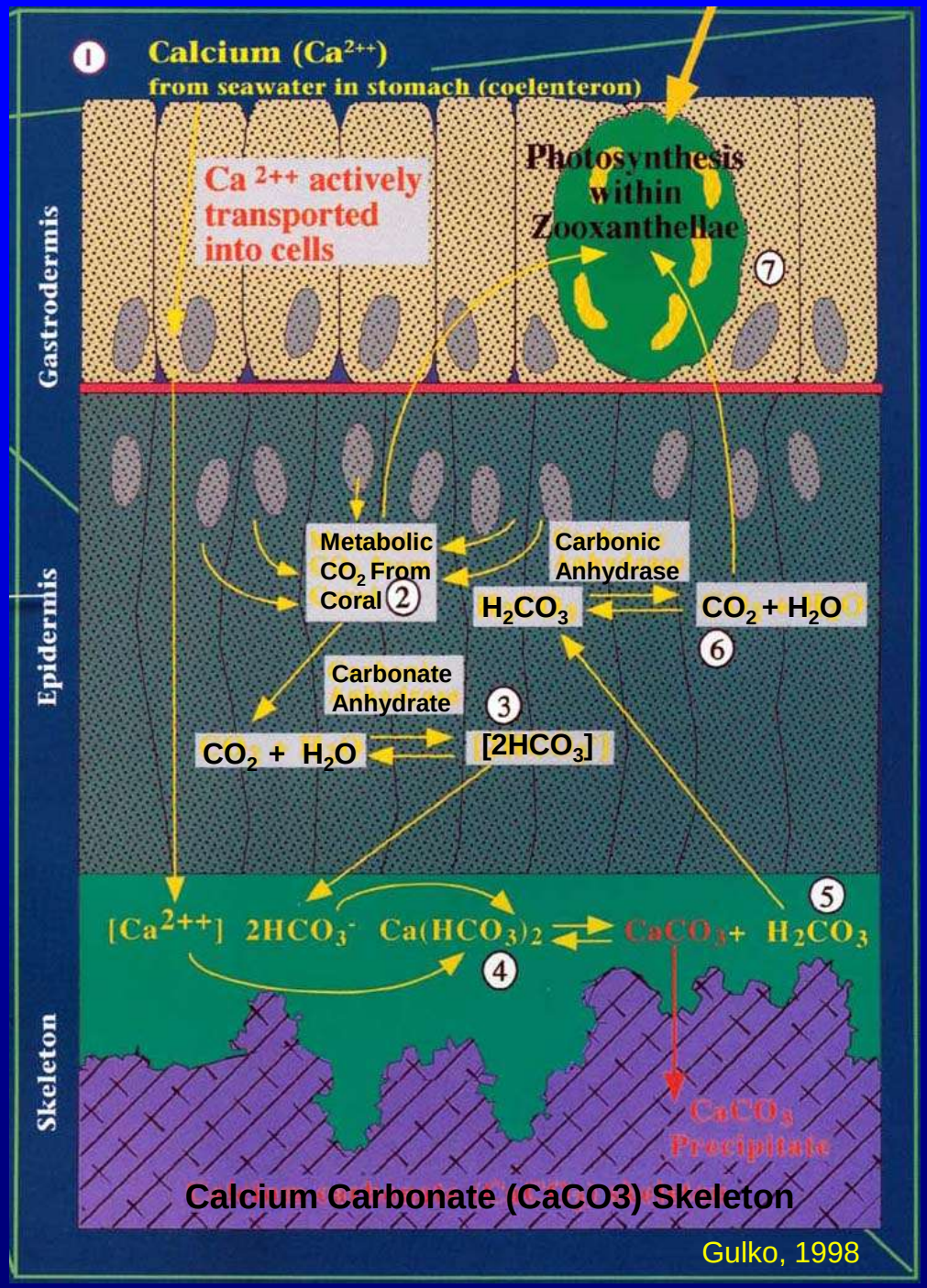
# Global $CO_2$ and Coral Reefs: Lessons from the Past

George D. Stanley
The University of Montana
Paleontology Center
Missoula USA

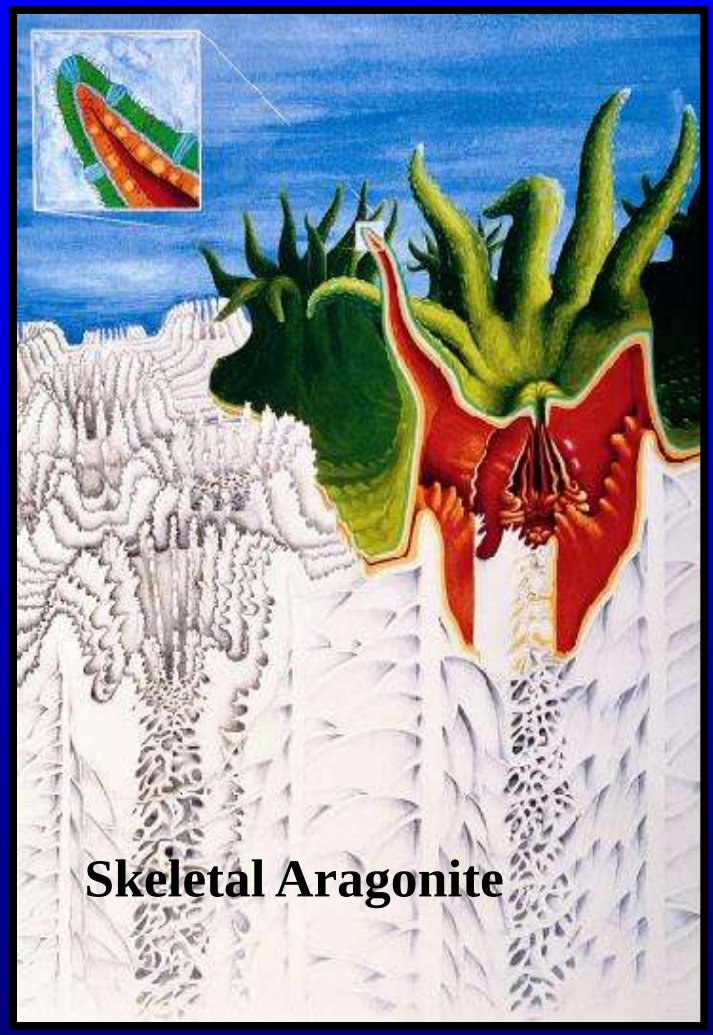

The History and Sedimentology of Ancient Reef Systems
The History and Sedimentology of Ancient Reef Systems
George D. Stanley, Jr.


Zooxanthellae

# SKELETON FORMATION




Gulko, 1998




Veron

NEWSFOCUS

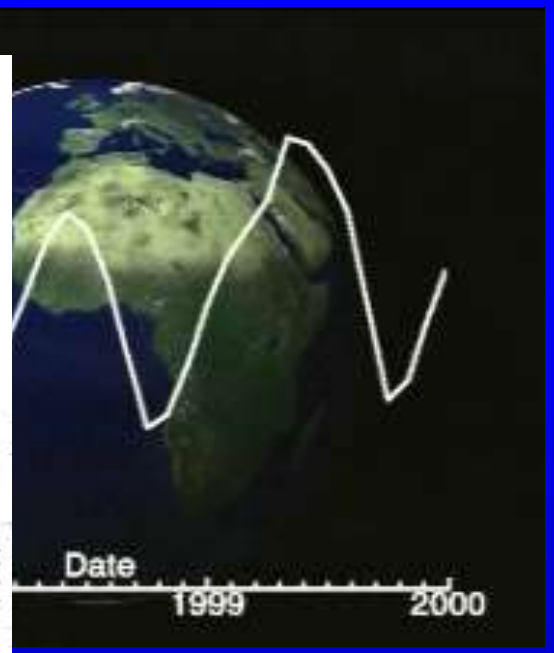
They've said it before, but this time climate scientists are saying it with feeling: The world is warming; it's not all natural, it's us; and if nothing is done, it will get a whole lot worse

**Scientists Tell Poli**
**We're All Warming**

North Wales Chronicle, 26th January, 2006, p 7

# Greenhouse effect 'just a natural cycle'

REGARDING the latter ... of years ago.
A Call To Support The ... Wind power has now ... water reactors, these to ... make a difference to the
Windfarms ... realises our old system ... price of that dwelling
Climate ... s t a i n a b l e
pening as ... v e l o p m e n t
ral cycle ... nission).
happens ... t of the visitors on
100,000 ye... sey see the wind-
at this mo... as a blot on our
we are ... cape, and only view
75,000th ... as a curiosity.
cycle. ... not in any way dis-
I do agre... condemn the use
sions of C... ernatives as a way
industry, ... oducing power, we
earth itself ... them, but I wish
breathing ... thought, true con-
including ... sion and better
help this ch... ing would take
Don't forg... especially in the
is growing ... and management
ing rate a... e alternatives.
more oxyg... could put this
atmospher... written subject to
ancestors ... ce used for all.
... and address supplied



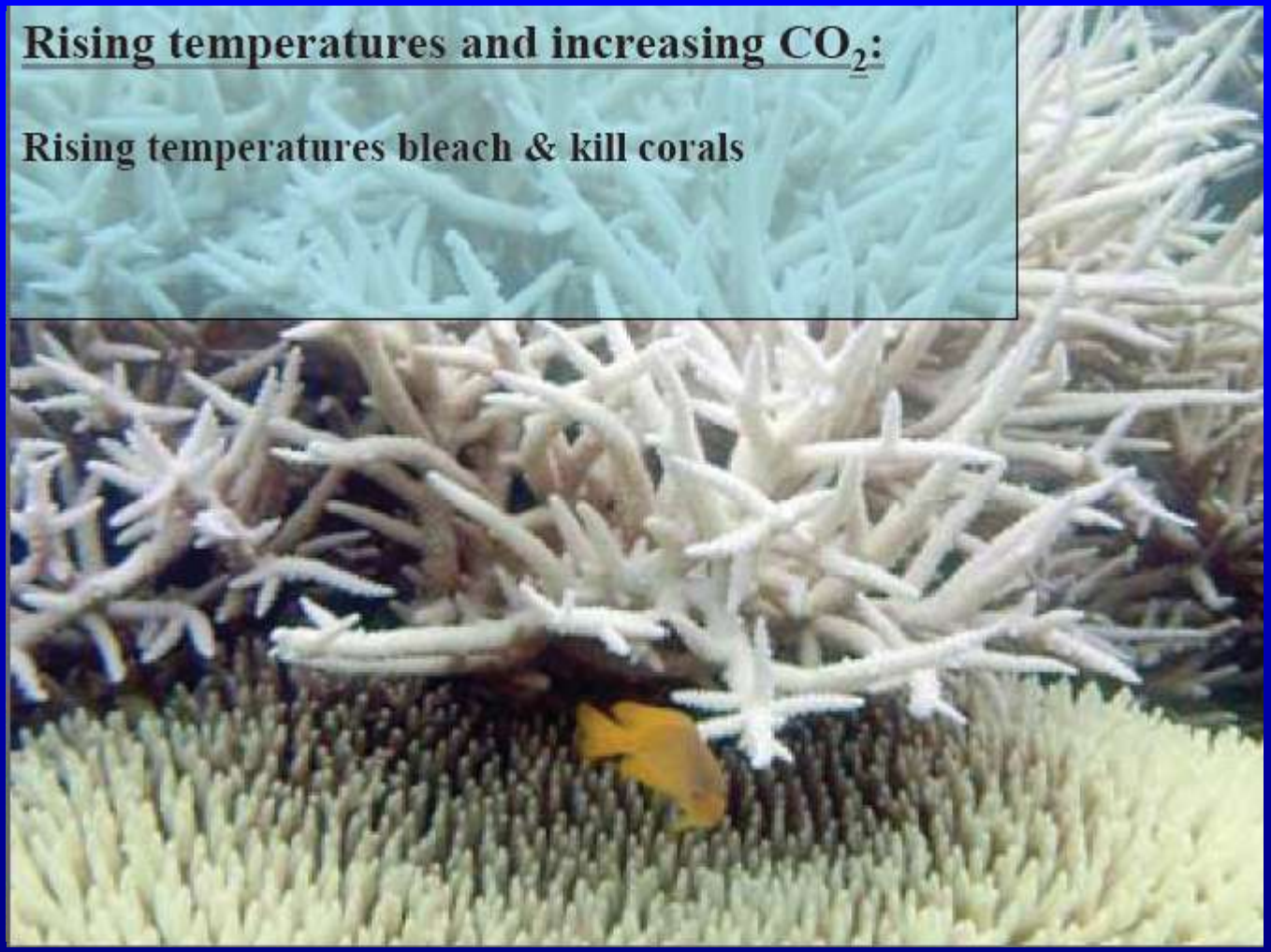

THE BRIDGE TRAGEDY • MURDOCH'S WAR PLAN

**Newsweek**

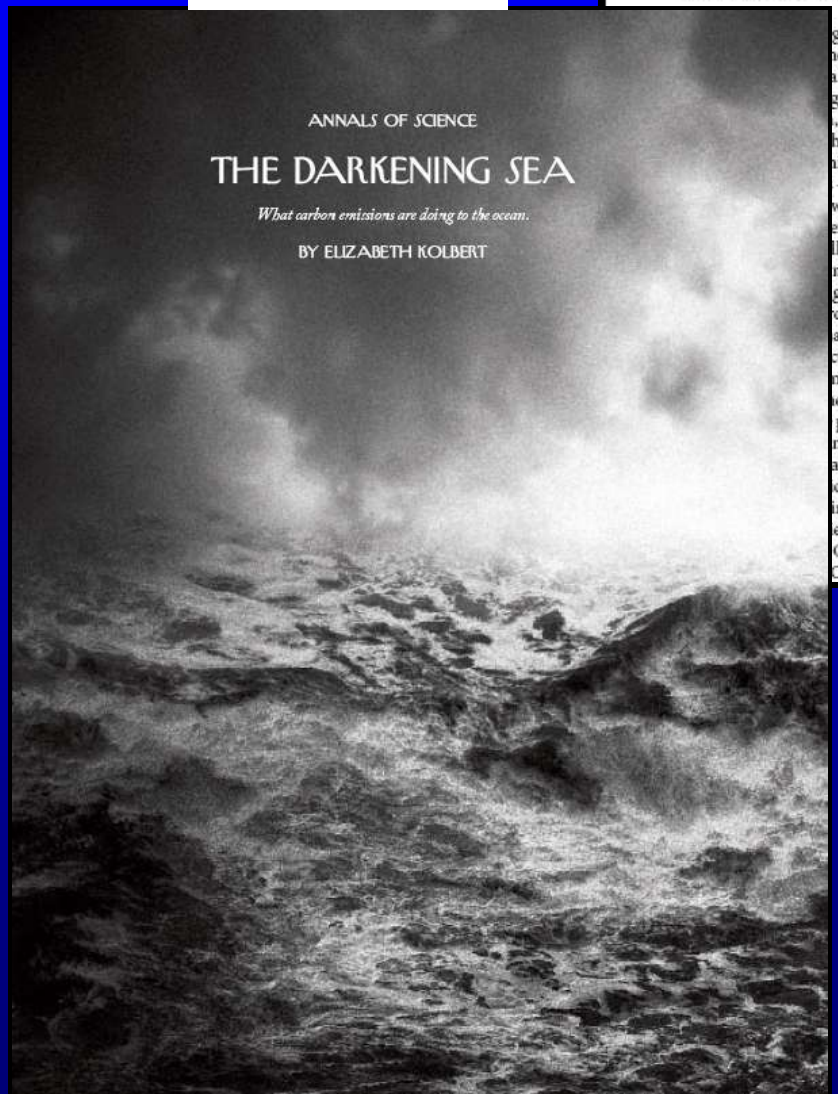
**Global Warming Is A Hoax.***

* Or so claim well-funded naysayers who still reject the overwhelming evidence of climate change. Inside the denial machine. By Sharon Begley

# Mass Bleaching of Corals



**New Yorker 2006**






NATURE|Vol 442|31 August 2006

# SICK SEAS

The rising level of carbon dioxide in the atmosphere is making the world's oceans more acidic. **Jacqueline Ruttimann** reports on the potentially catastrophic effect this could have on marine creatures.

gine a tonne of water: it is
not-very-deep baths. Get-
a billion tonnes of water is
ge. That would be a simi-
, woman and child on the
h of flow for the Nile. To
hind, go further still, to a
— enough water to give
worth of the Nile instead
ere are dwarf planets that
llion billion tonnes. Yet
more.

gine something so vast,
der to imagine changing
anging the oceans. From
tic, the seas are sucking
nissions of carbon diox-
e excess belched into the
past two centuries from
nd cement manufactur-
arbon dioxide dissolves
d is produced: as a result
ng more acidic. "It's basic
e Kleypas, a marine ecol-
Center for Atmospheric
Colorado. "It's hard to say

unprecedented. Before the industrial revolution, the rise in the level of carbon dioxide in the atmosphere was relatively slow — giving oceans time to circulate the waters being made more acidic in the shallows with acid-neutralizing carbonate sediments in the depths.

In the past few decades, carbon dioxide has been building up far more quickly, and the ocean is becoming acidified at a rate that outpaces the action of sedimentary antacids. The rate of change is perhaps 100 times anything seen in the past hundreds of millennia, as suggested by isotope studies of ancient sediments. In the century to come, sea creatures will find themselves in conditions that their ancestors never had to face. These organisms have never been forced to adapt to lower pH, says Ulf Riebesell, a marine biogeochemist at the Leibniz Institute for Marine Sciences in Germany. "They've never seen this before in their evolution."

## Acid attack

The acidified waters eat away at the carbonate skeletons that protect many marine organisms. By some estimates, calcification rates will

## Rising temperatures and increasing $CO_2$:

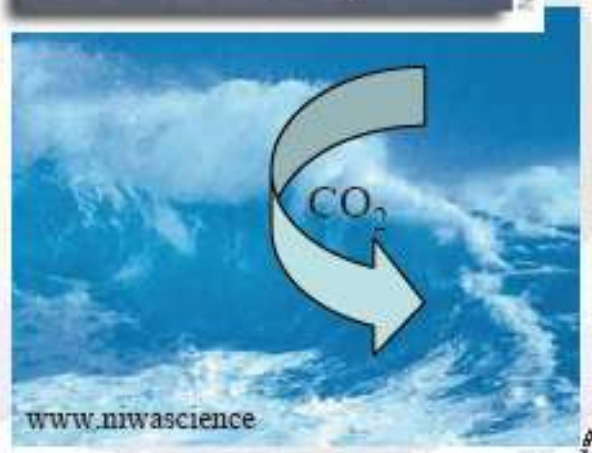
Rising temperatures bleach & kill corals

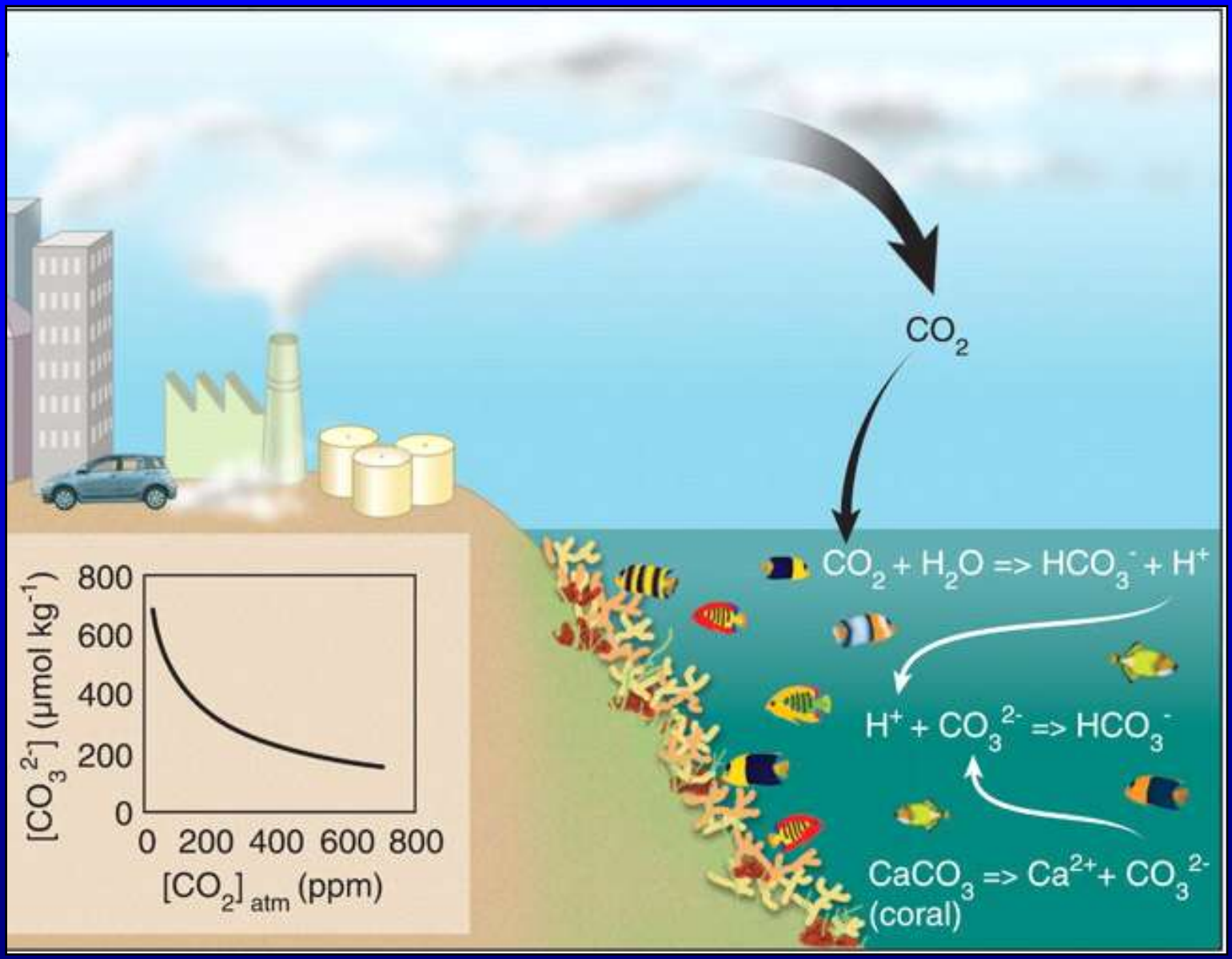
Rising $CO_2$ threatens reef structure

# Impacts of Ocean Acidification on Coral Reefs

## Surface Ocean Uptake of $CO_2$

≈ 48% of anthropogenic $CO_2$ taken up by the ocean

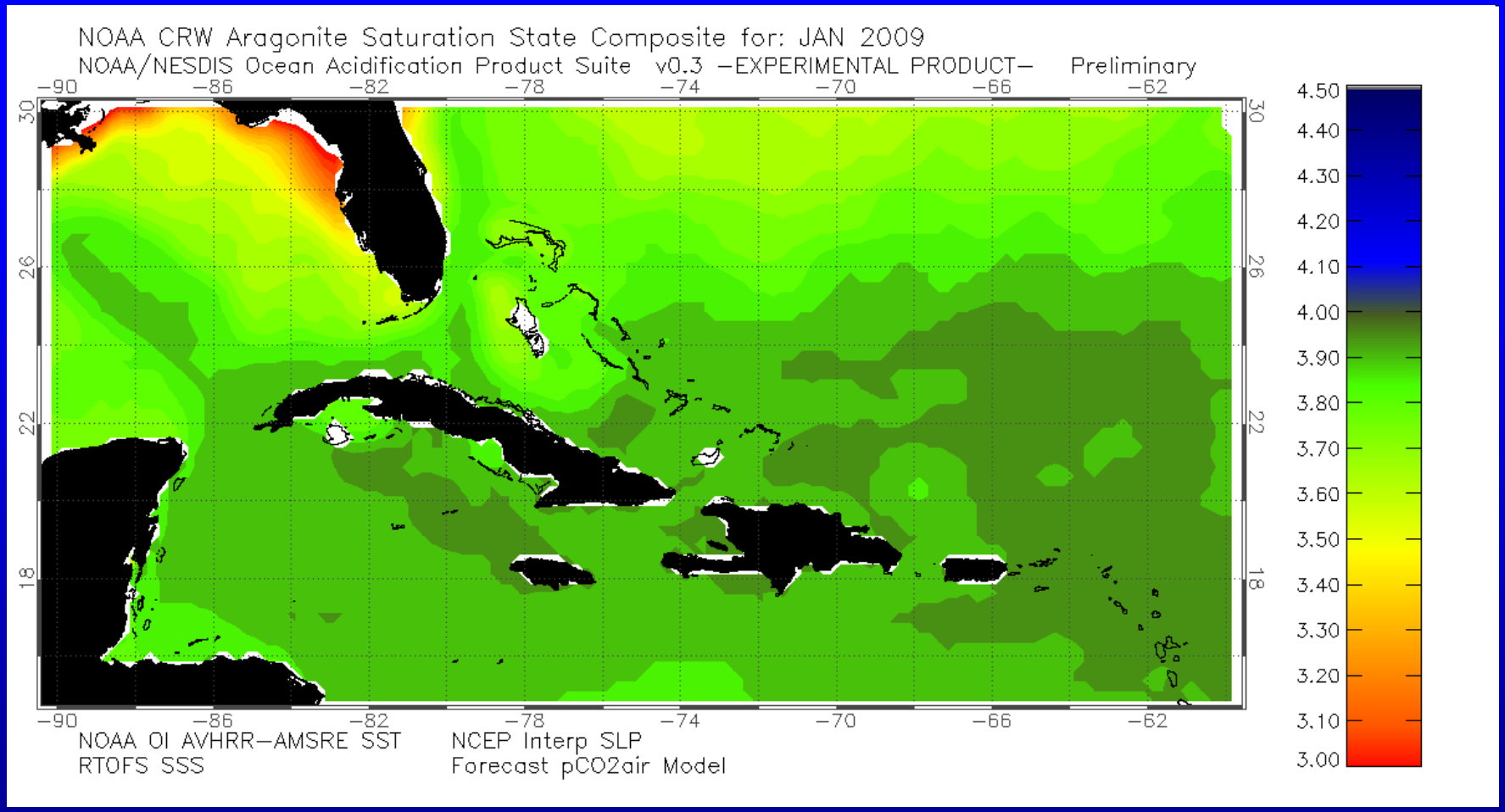

$CO_2$
$CO_2 + H_2O \Rightarrow HCO_3^- + H^+$
$H^+ + CO_3^{2-} \Rightarrow HCO_3^-$
$CaCO_3 \Rightarrow Ca^{2+} + CO_3^{2-}$
(coral)
$[CO_3^{2-}]$ (µmol $kg^{-1}$)
800
600
400
200
0
0 200 400 600 800
$[CO_2]_{atm}$ (ppm)

# Carbonate Saturation State Ω

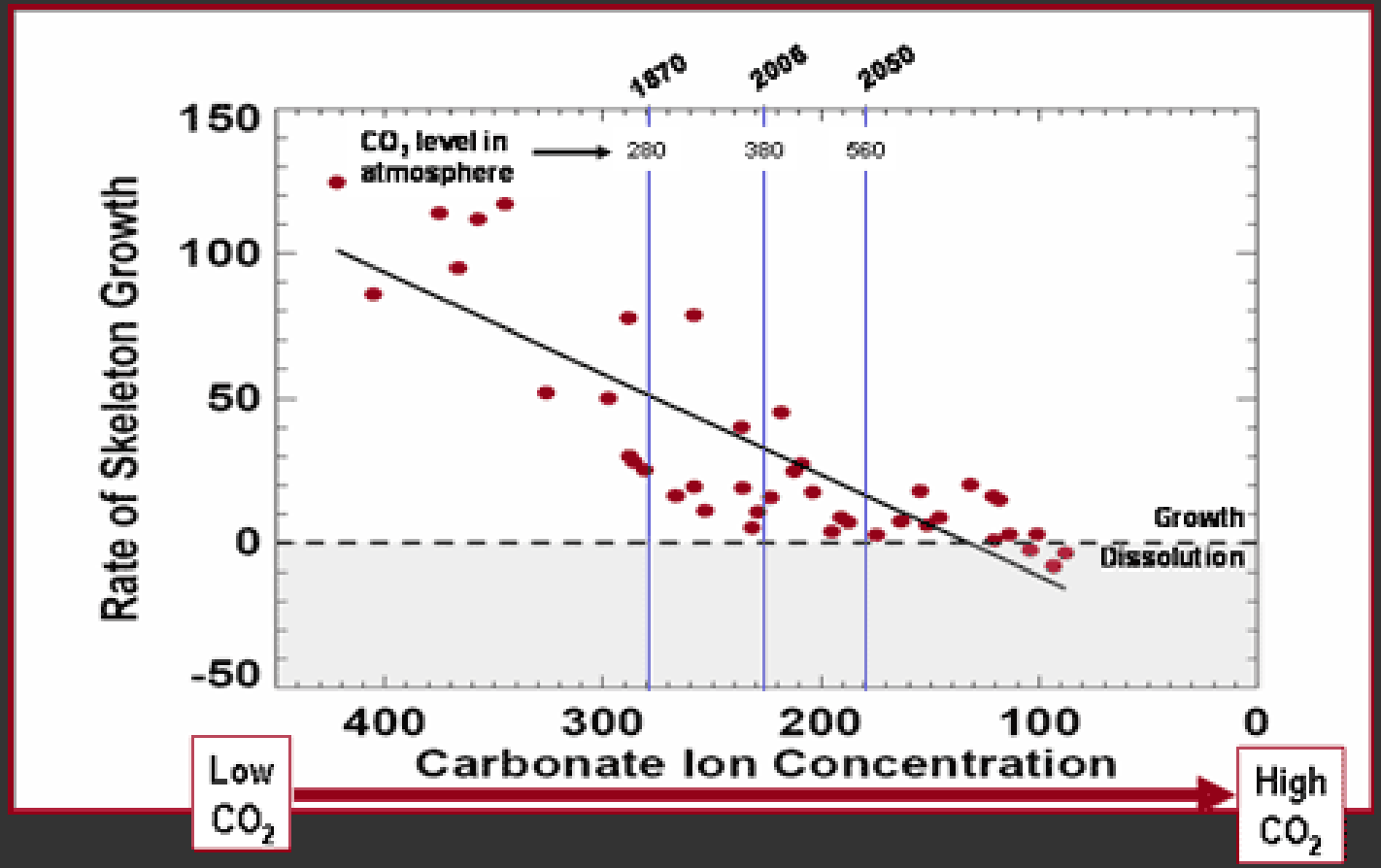
Dissolution/precipitation of inorganic marine CaCO3 controlled by saturation state:

$$\Omega = [Ca2+][CO_3^{2-}]/Ksp$$

where Ksp is the solubility product


NOAA CRW Aragonite Saturation State Composite for: JAN 2009
NOAA/NESDIS Ocean Acidification Product Suite v0.3 –EXPERIMENTAL PRODUCT– Preliminary
−90
−86
−82
−78
−74
−70
−66
−62
30
26
22
18
4.50
4.40
4.30
4.20
4.10
4.00
3.90
3.80
3.70
3.60
3.50
3.40
3.30
3.20
3.10
3.00
NOAA OI AVHRR–AMSRE SST
RTOFS SSS
NCEP Interp SLP
Forecast pCO2air Model

# Skeletal Growth in the B2 Reef Decreased Under Future $CO_2$ Conditions

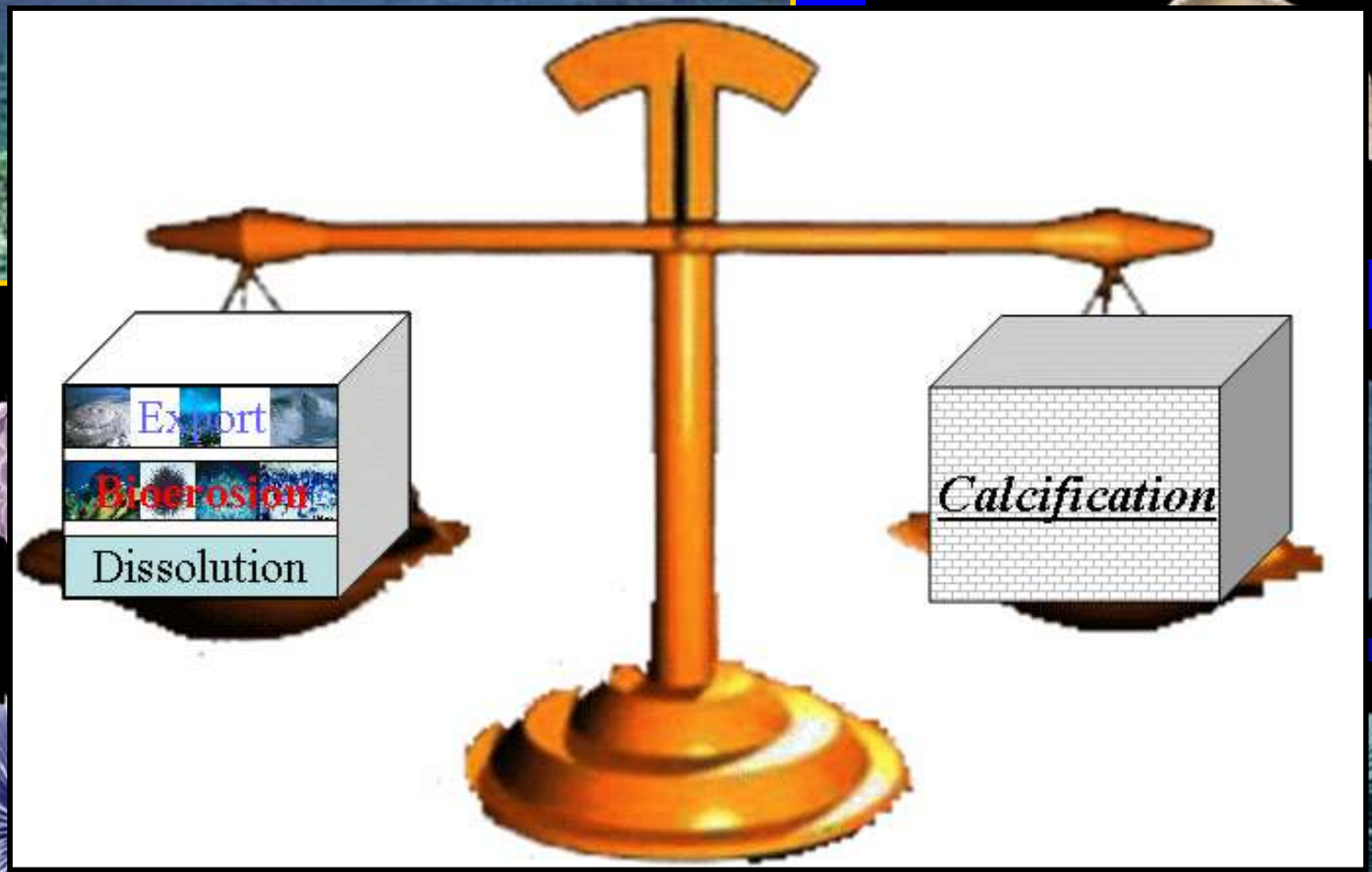



*Data from Chris Langdon*

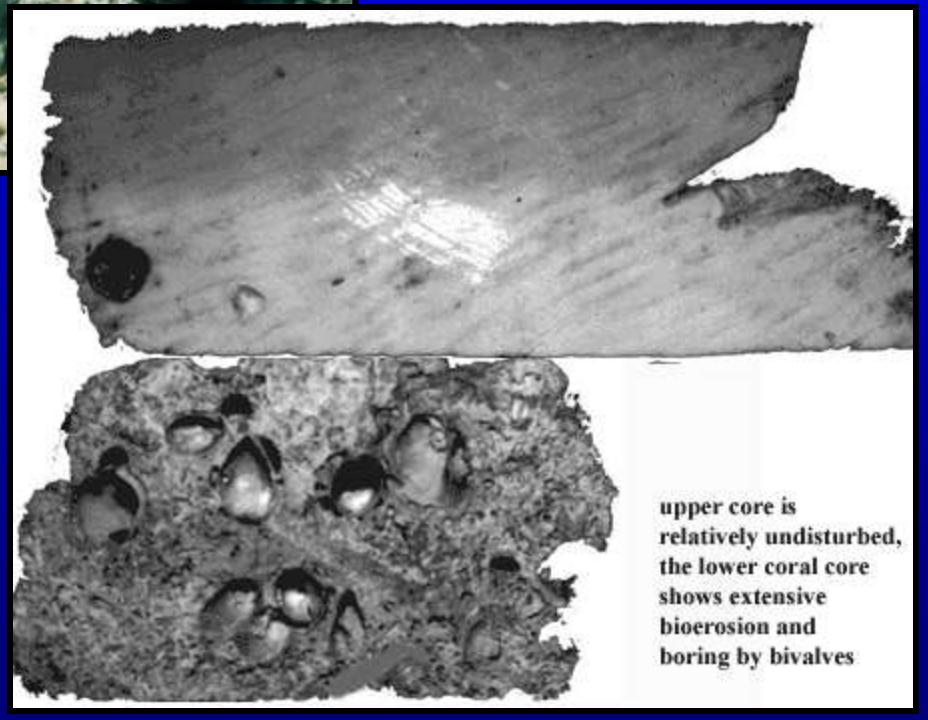
# Ocean Acidification


**Carbonate saturation and predicted rise in $pCO_2$**

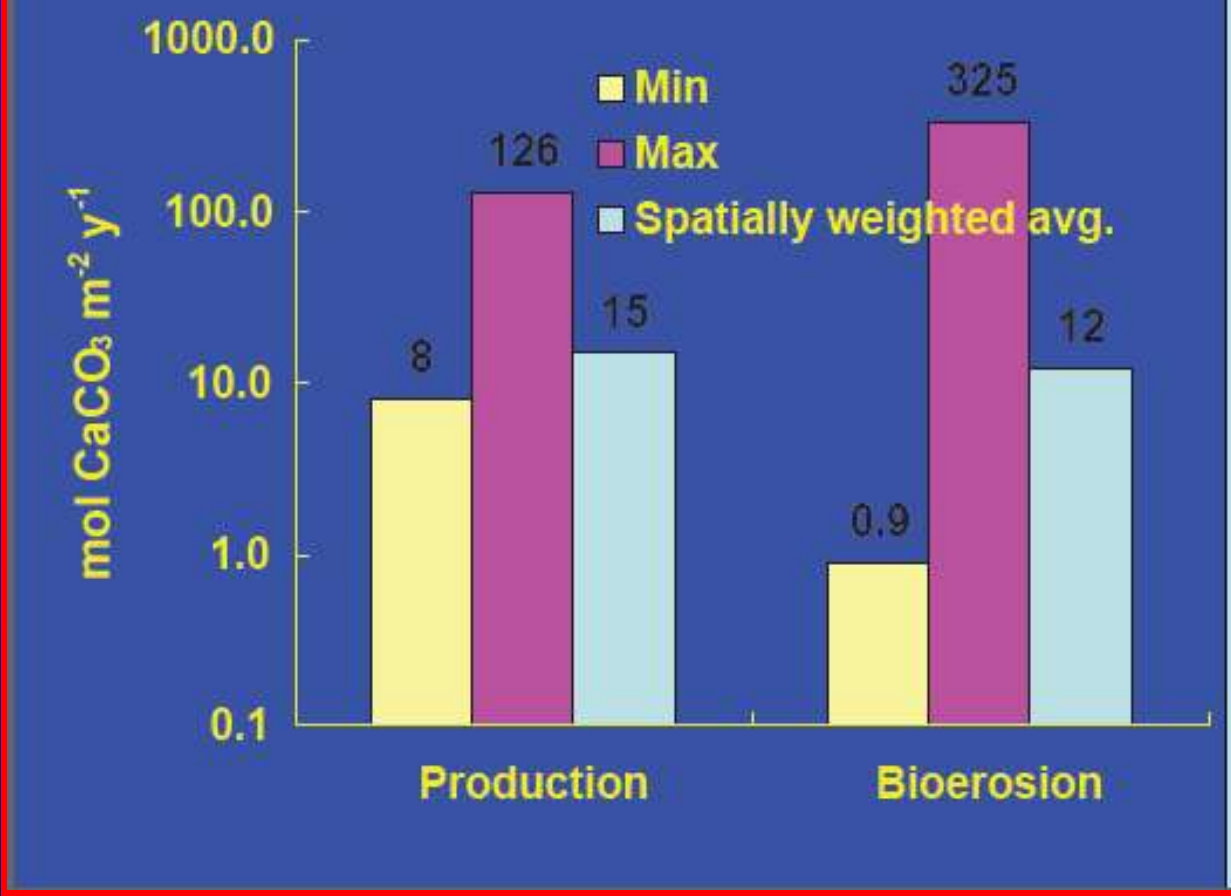
# Calcification/Dissolution Response



# BIOEROSION


upper core is
relatively undisturbed,
the lower coral core
shows extensive
bioerosion and
boring by bivalves

# Balance of carbonate production and destruction on coral reefs




A reduction in calcification of 20% could push many coral reefs into a negative mass balance.

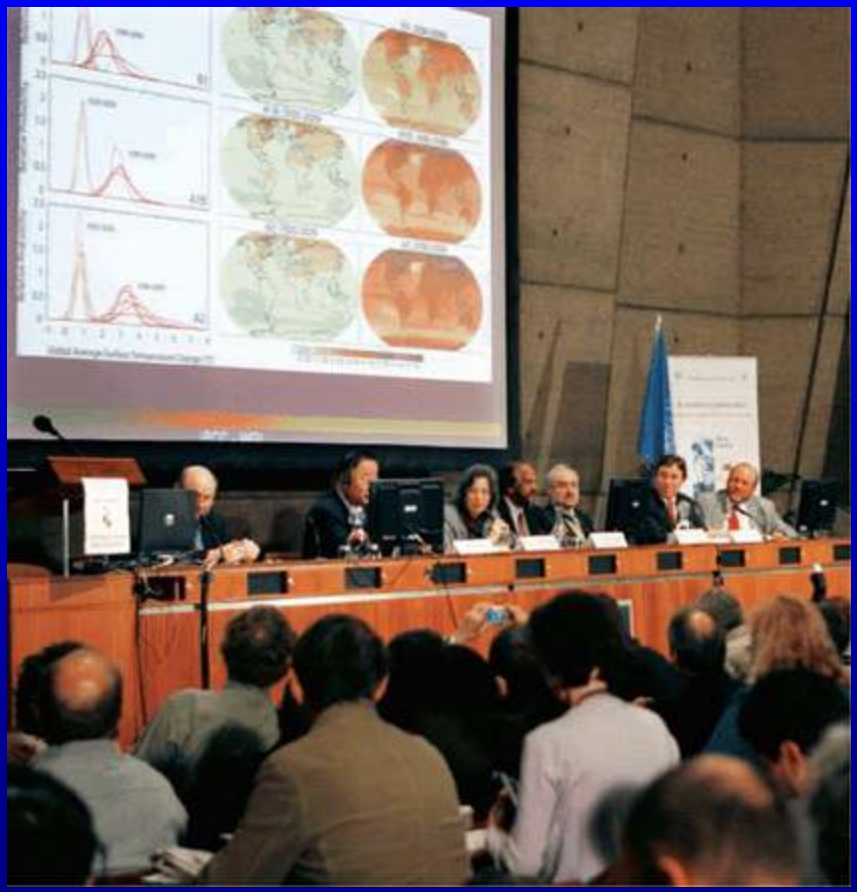

# Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers

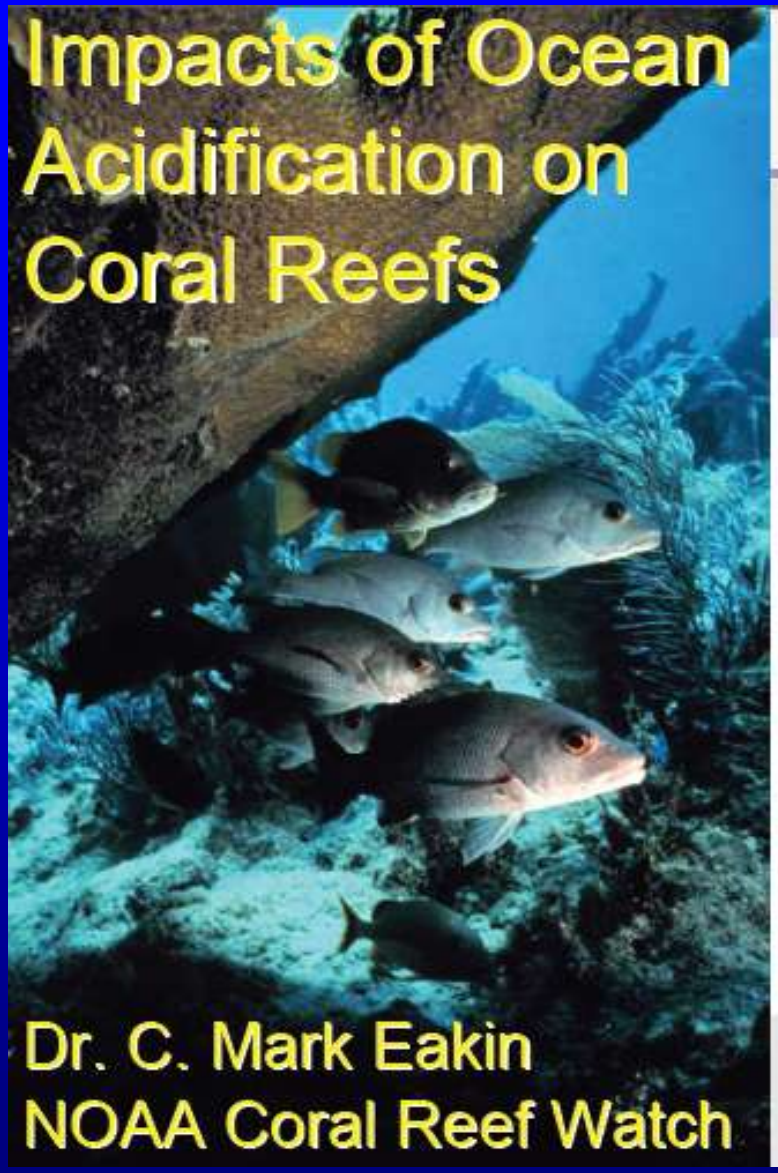
## A Guide for Future Research

Report of a workshop sponsored by

NSF NOAA USGS

JA Kleypas . RA Feely . VJ Fabry
C Langdon . CL Sabine . LL Robbins

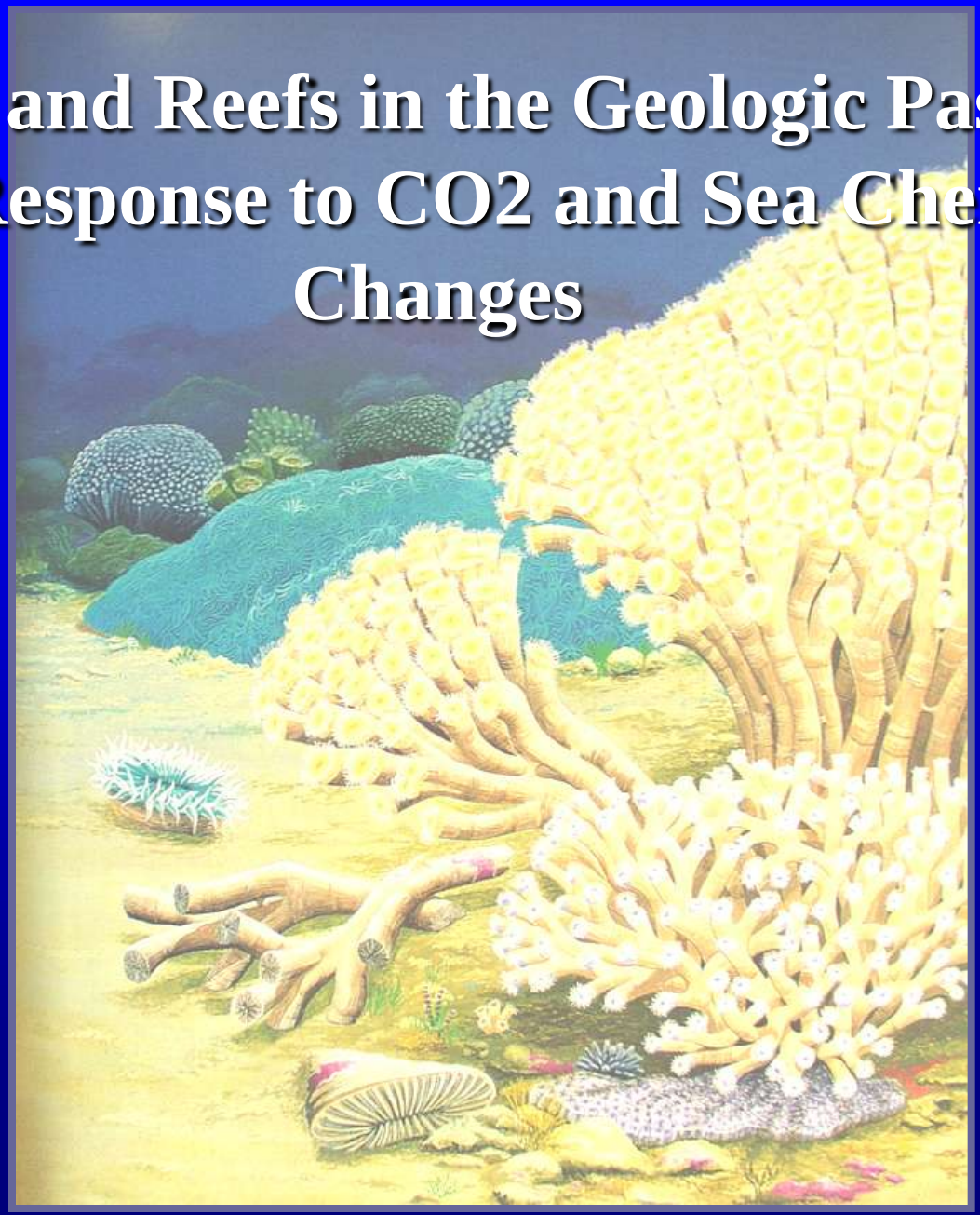


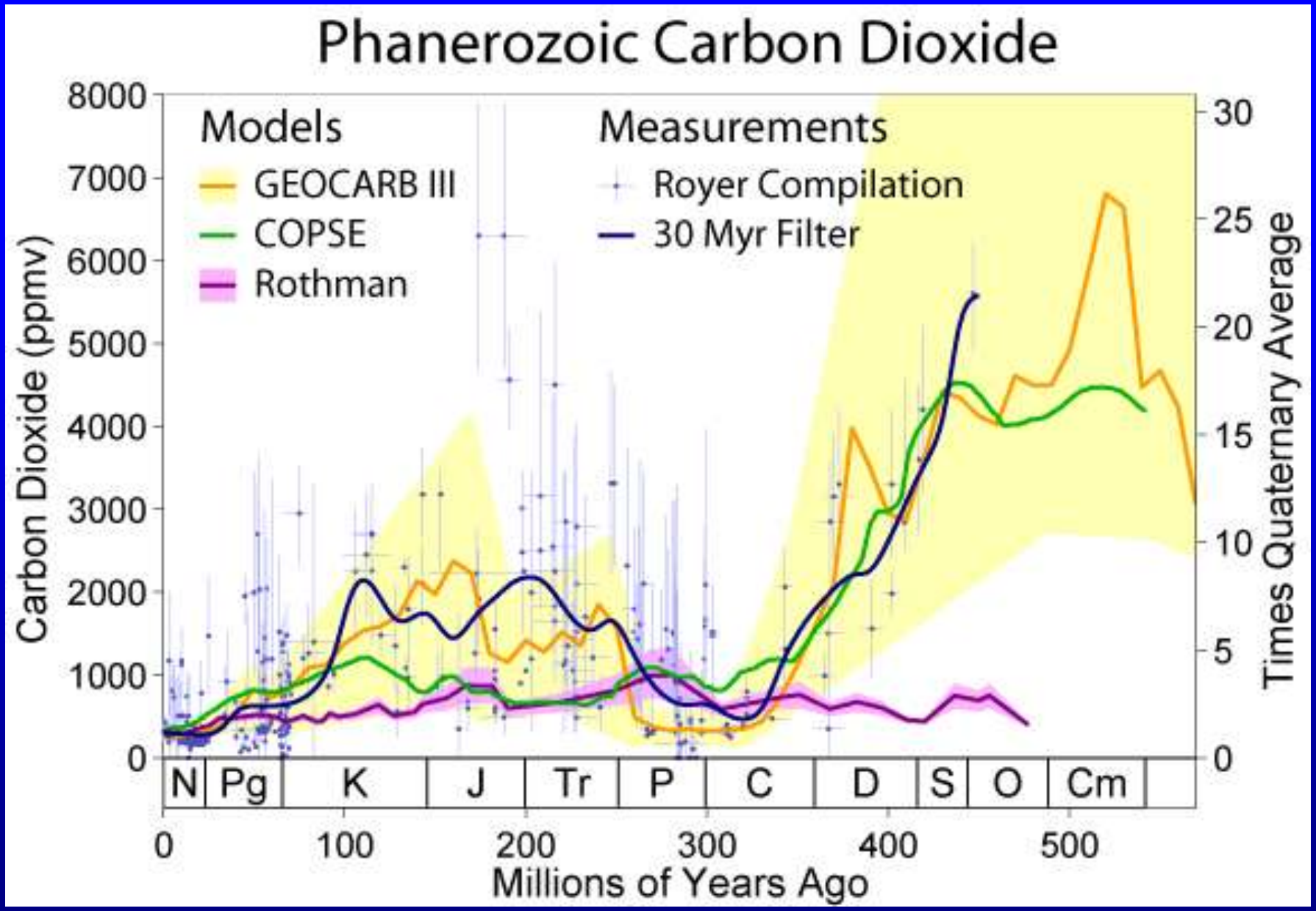



NOAA coral reef CONSERVATION PROGRAM

- Ocean chemistry is changing to a state that has not occurred for hundreds of thousands of years
- Shell-building in marine organisms may slow down
- Reef-building may decrease, stop, or reverse
- Fundamental changes may occur in open-ocean and coastal marine ecosystems

# Corals and Reefs in the Geologic Past and Their Response to CO2 and Sea Chemistry Changes





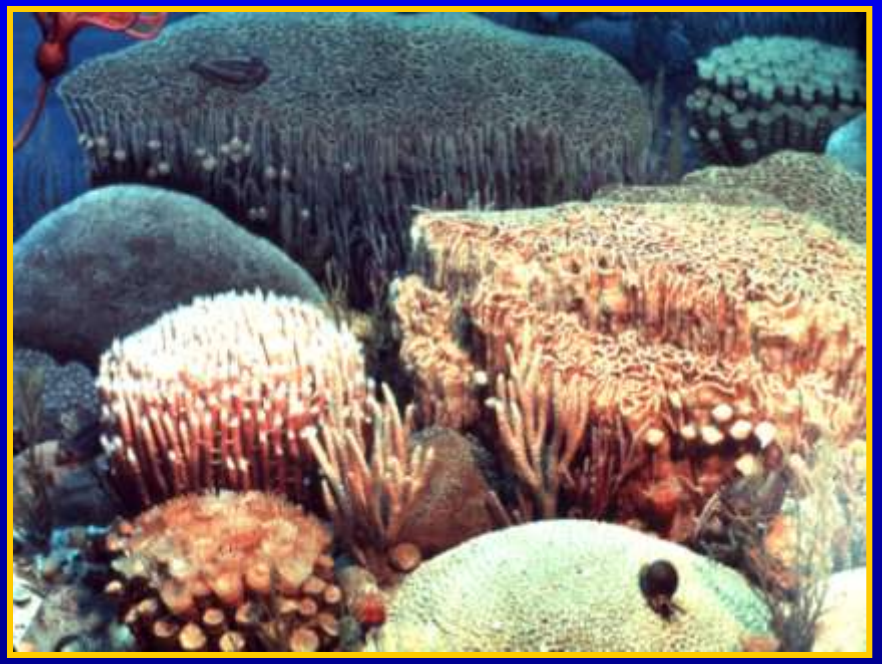

GEOCARB III (Berner and Kothavala 2001); COPSE (Bergmann et al. 2004); Rothman (2001); Royer et al. (2004).

**Robert A. Rohde Global Warming Art Project**

**Aragonite**

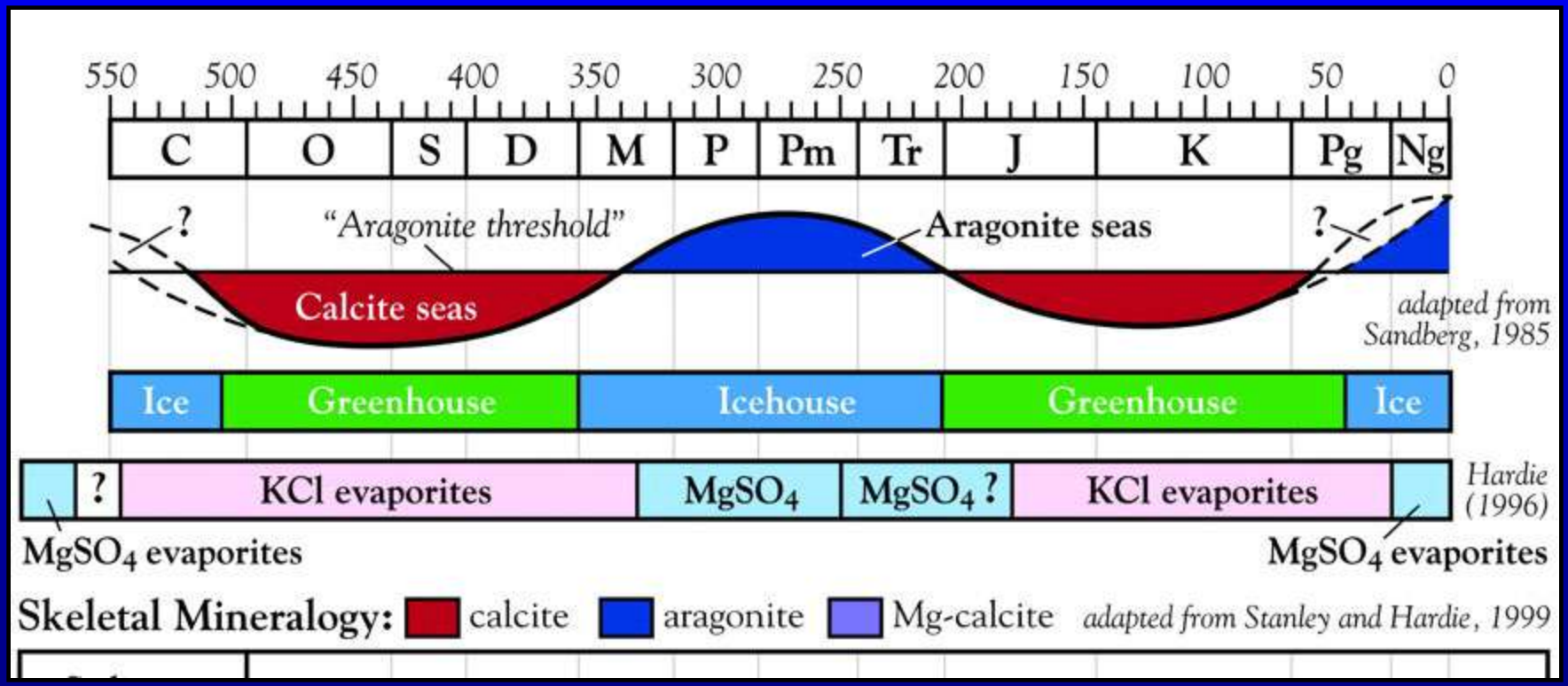
Modern Corals Secrete Skeletons of $CaCO_2$ in form of Aragonite (Mg rich)

# Ancient Paleozoic Corals secreted Skeletons of $CaCO_2$ in the form of calcite (Ca rich)

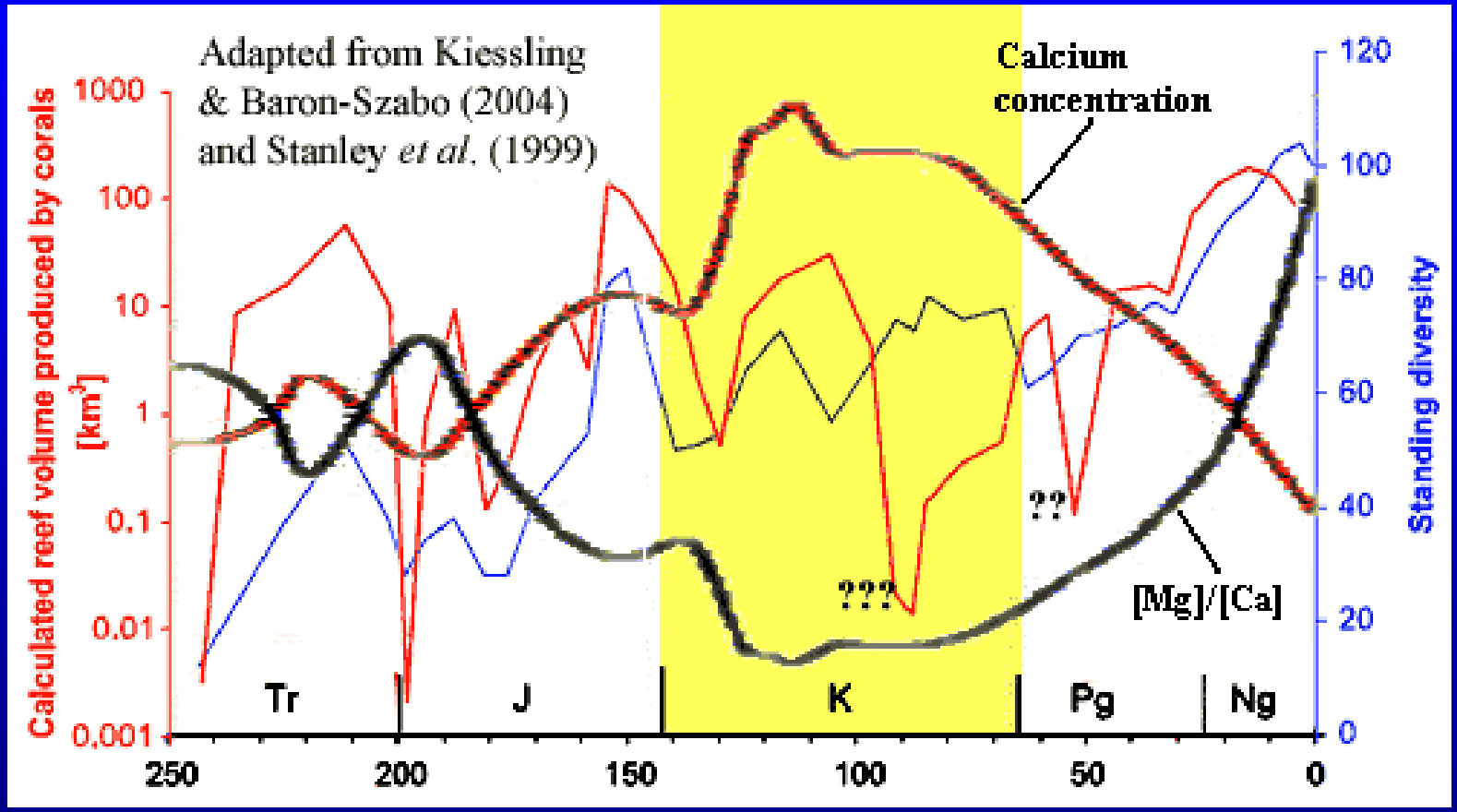


# In geologic time Earth's Oceans have changed in Mg/Ca ratios in cycles favoring either calcite or

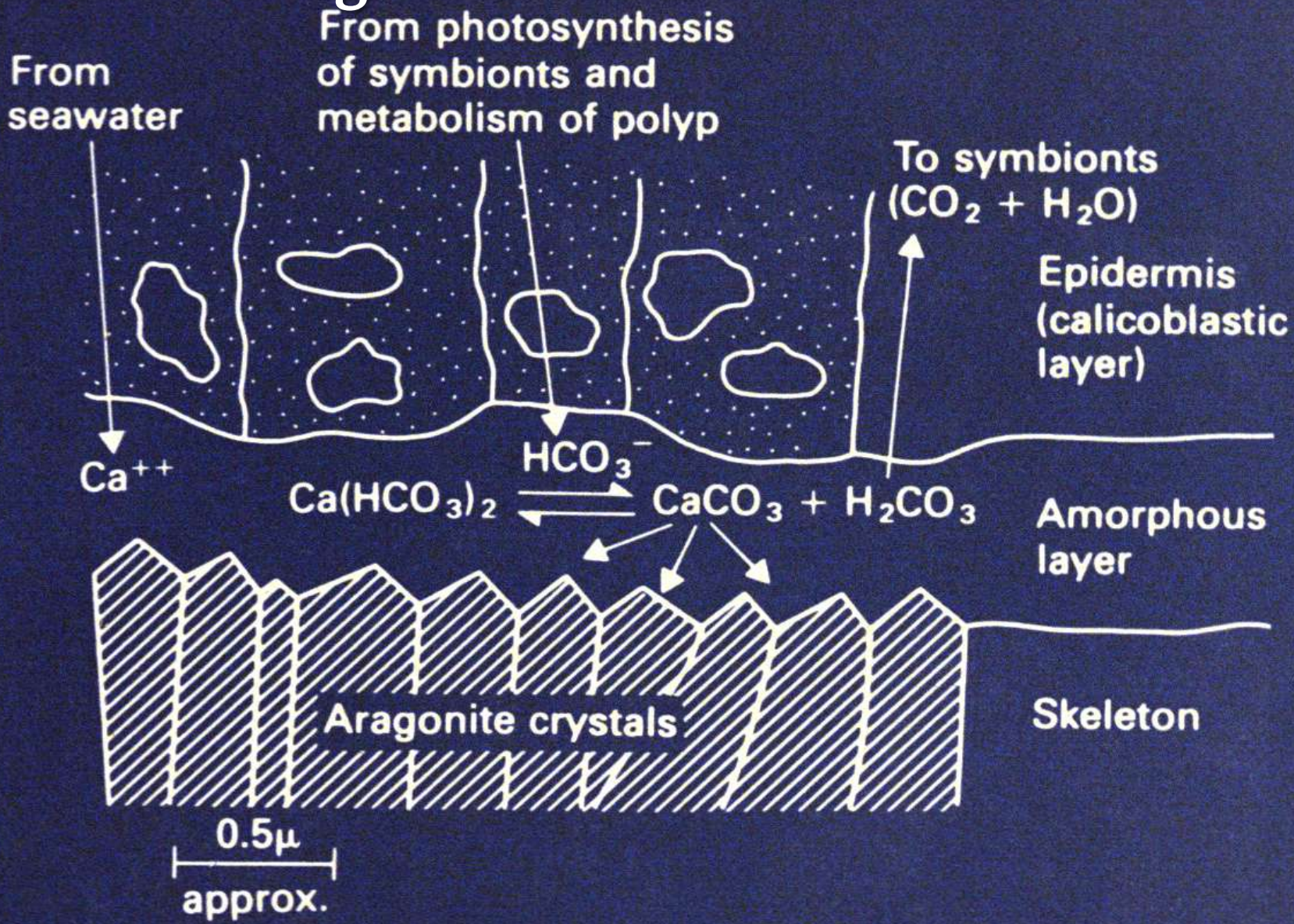
## aragonite as the preferred skeleton



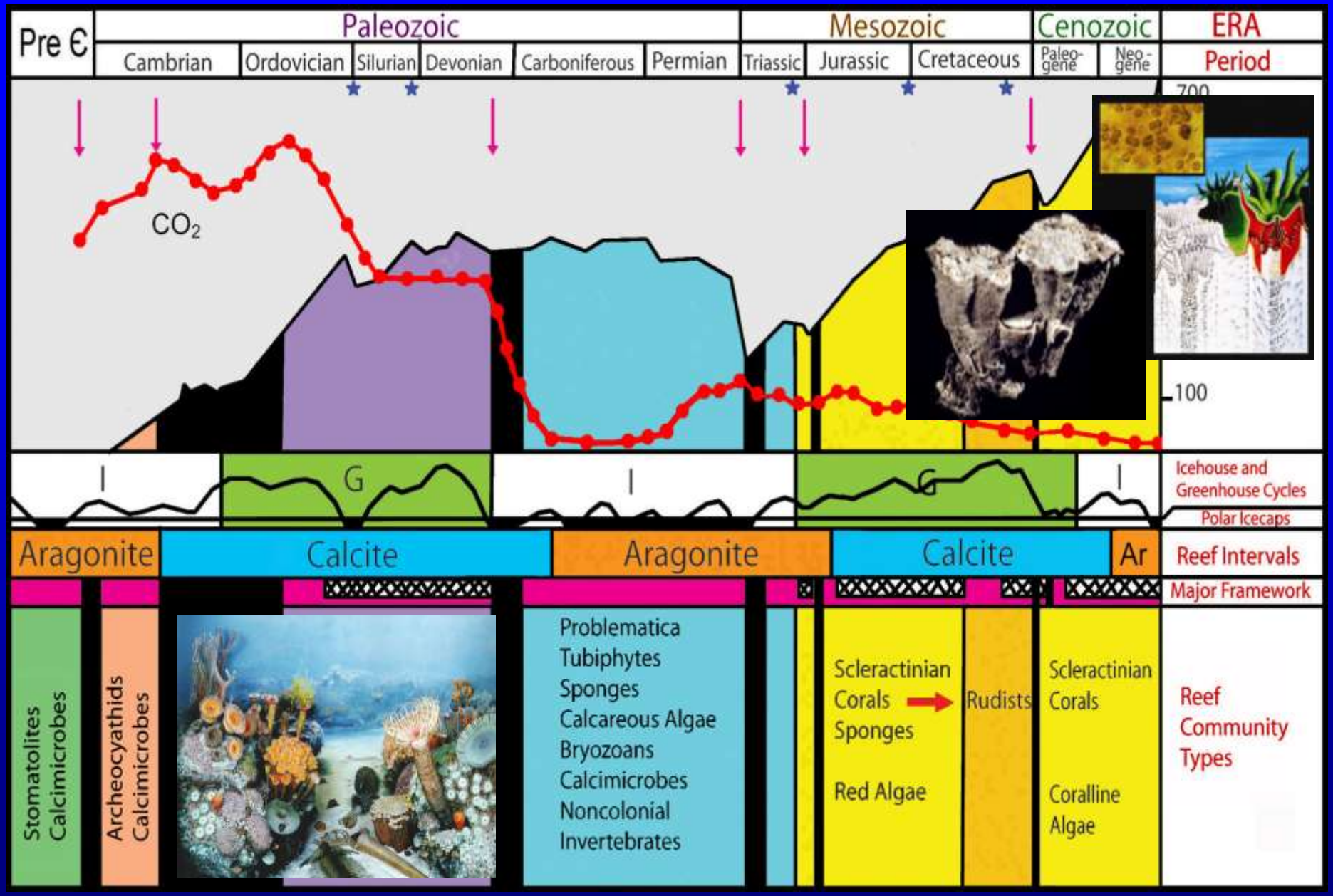
# Not Just $CO_2$ Concentration

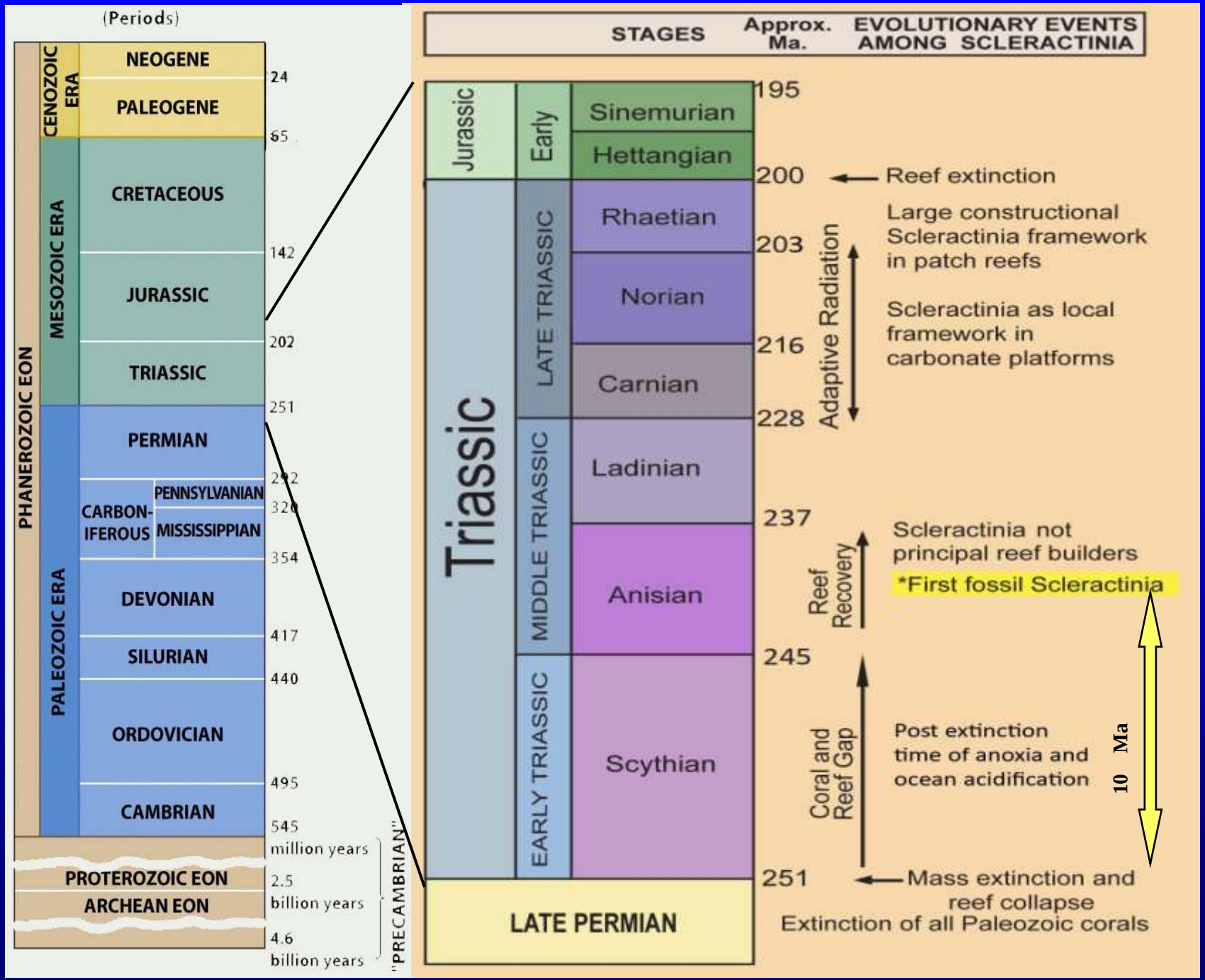


# Energetics of the Reaction



# Justin Reis
# Woods Hole Laboratory


Pre Є
Paleozoic
Mesozoic
Cenozoic
ERA
Cambrian
Ordovician
Silurian
Devonian
Carboniferous
Permian
Triassic
Jurassic
Cretaceous
Paleo-gene
Neo-gene
Period
700
100
CO2
I
G
I
G
I
Icehouse and Greenhouse Cycles
Polar Icecaps
Aragonite
Calcite
Aragonite
Calcite
Ar
Reef Intervals
Major Framework
Stomatolites Calcimicrobes
Archeocyathids Calcimicrobes
Problematica
Tubiphytes
Sponges
Calcareous Algae
Bryozoans
Calcimicrobes
Noncolonial Invertebrates
Scleractinian Corals
Sponges
Red Algae
Rudists
Scleractinian Corals
Coralline Algae
Reef Community Types


(Periods)
PHANEROZOIC EON
CENOZOIC ERA
NEOGENE
PALEOGENE
24
65
MESOZOIC ERA
CRETACEOUS
142
JURASSIC
202
TRIASSIC
251
PALEOZOIC ERA
PERMIAN
292
CARBON-IFEROUS
PENNSYLVANIAN
320
MISSISSIPPIAN
354
DEVONIAN
417
SILURIAN
440
ORDOVICIAN
495
CAMBRIAN
545
million years
PROTEROZOIC EON
2.5
billion years
ARCHEAN EON
4.6
billion years
"PRECAMBRIAN"
STAGES
Approx. Ma.
EVOLUTIONARY EVENTS AMONG SCLERACTINIA
Jurassic
Triassic
Early
LATE TRIASSIC
MIDDLE TRIASSIC
EARLY TRIASSIC
Sinemurian
Hettangian
Rhaetian
Norian
Carnian
Ladinian
Anisian
Scythian
LATE PERMIAN
195
200
203
216
228
237
245
251
Reef extinction
Large constructional Scleractinia framework in patch reefs
Scleractinia as local framework in carbonate platforms
Adaptive Radiation
Scleractinia not principal reef builders
*First fossil Scleractinia
Reef Recovery
Post extinction time of anoxia and ocean acidification
Coral and Reef Gap
10 Ma
Mass extinction and reef collapse
Extinction of all Paleozoic corals

(Periods)

PHANEROZOIC EON

CENOZOIC ERA
- NEOGENE
- PALEOGENE

24

65

MESOZOIC ERA
- CRETACEOUS
- JURASSIC
- TRIASSIC

142

202

251

PALEOZOIC ERA
- PERMIAN
- CARBON-IFEROUS
  - PENNSYLVANIAN
  - MISSISSIPPIAN
- DEVONIAN
- SILURIAN
- ORDOVICIAN
- CAMBRIAN

292

320

354

417

440

495

545 million years

PROTEROZOIC EON

2.5 billion years

ARCHEAN EON

"CAMBRIAN"

**Fossil** ←

**DNA** ←

# Naked Coral Hypothesis (Stanley & Fautin 2001) (Stanley, 2003)

Idea that the coral skeleton is ephemeral with respect to calcification (i.e. can exist as a soft-bodied anemone or with a skeleton)

**Triassic Coral**

**Modern Scleractinian = Hexacoral**

**Modern Corallimorpharian**

PNAS June 13, 2006

# Naked corals: Skeleton loss in Scleractinia

Mónica Medina[†‡], Allen G. Collins[§], Tori L. Takaoka[†], Jennifer V. Kuehl[†], and Jeffrey L. Boore[†¶]

[†]Department of Evolutionary Genomics, Department of Energy Joint Genome Institute, 2800 Mitchell Drive, Walnut Creek, CA 94598; [§]National Systematics Laboratory, National Oceanic and Atmospheric Administration Fisheries Service, National Museum of Natural History, MRC 153, Smithsonian Institution, Washington, DC 20013-7012; and [¶]Department of Integrative Biology, University of California Berkeley, 3060 Valley Life Sciences Building, Berkeley, CA 94720

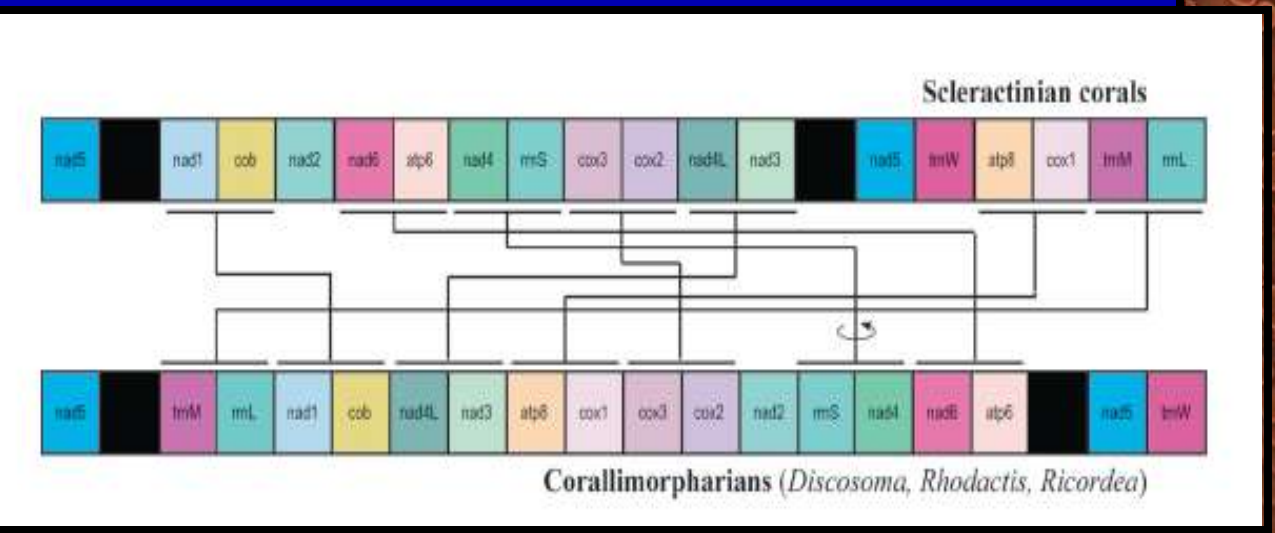
Communicated by James W. Valentine, University of California, Berkeley, CA, April 27, 2006 (received for review January 14, 2006)

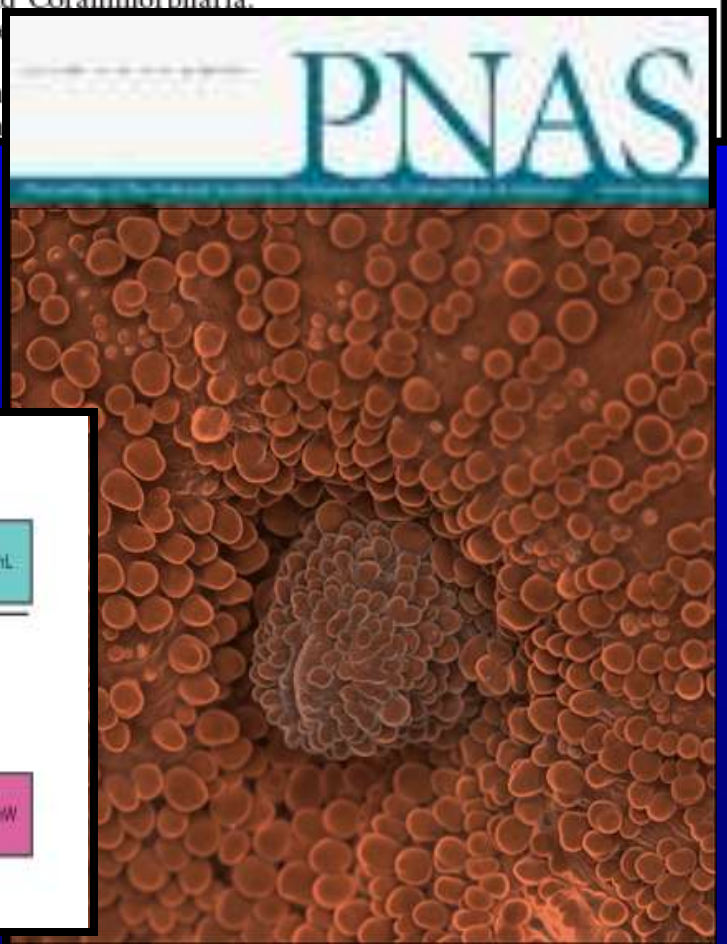
**Stony corals, which form the framework for modern reefs, are classified as Scleractinia (Cnidaria, Anthozoa, and Hexacorallia) in reference to their external aragonitic skeletons. However, persistent notions, collectively known as the "naked coral" hypothesis, hold that the scleractinian skeleton does not define a natural group. Three main lines of evidence have suggested that some**

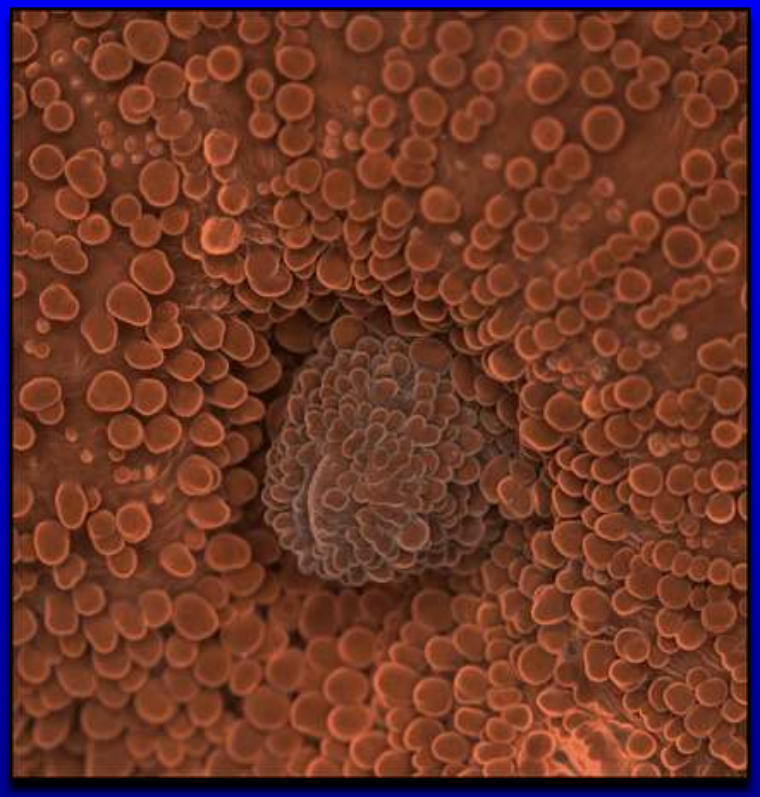
teristics that may be synapomorphies for the clade uniting Scleractinia and Corallimorpharia.

The second s
hypothesis has
phylogenetic an
of Hexacorallia

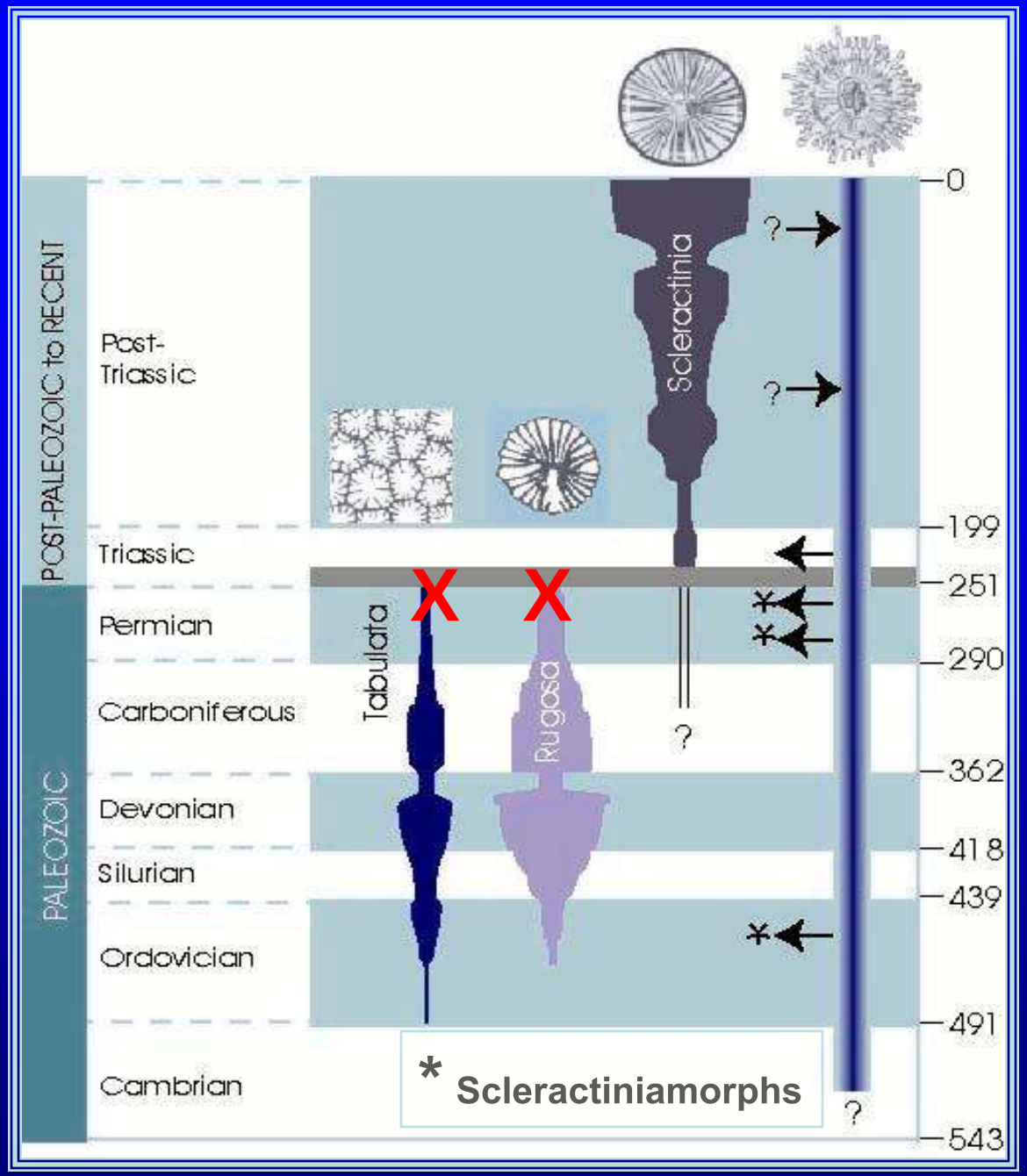
- **Complete mitrochondrial data**
- **Genetic closeness of one clade of coral with a group of anemone**



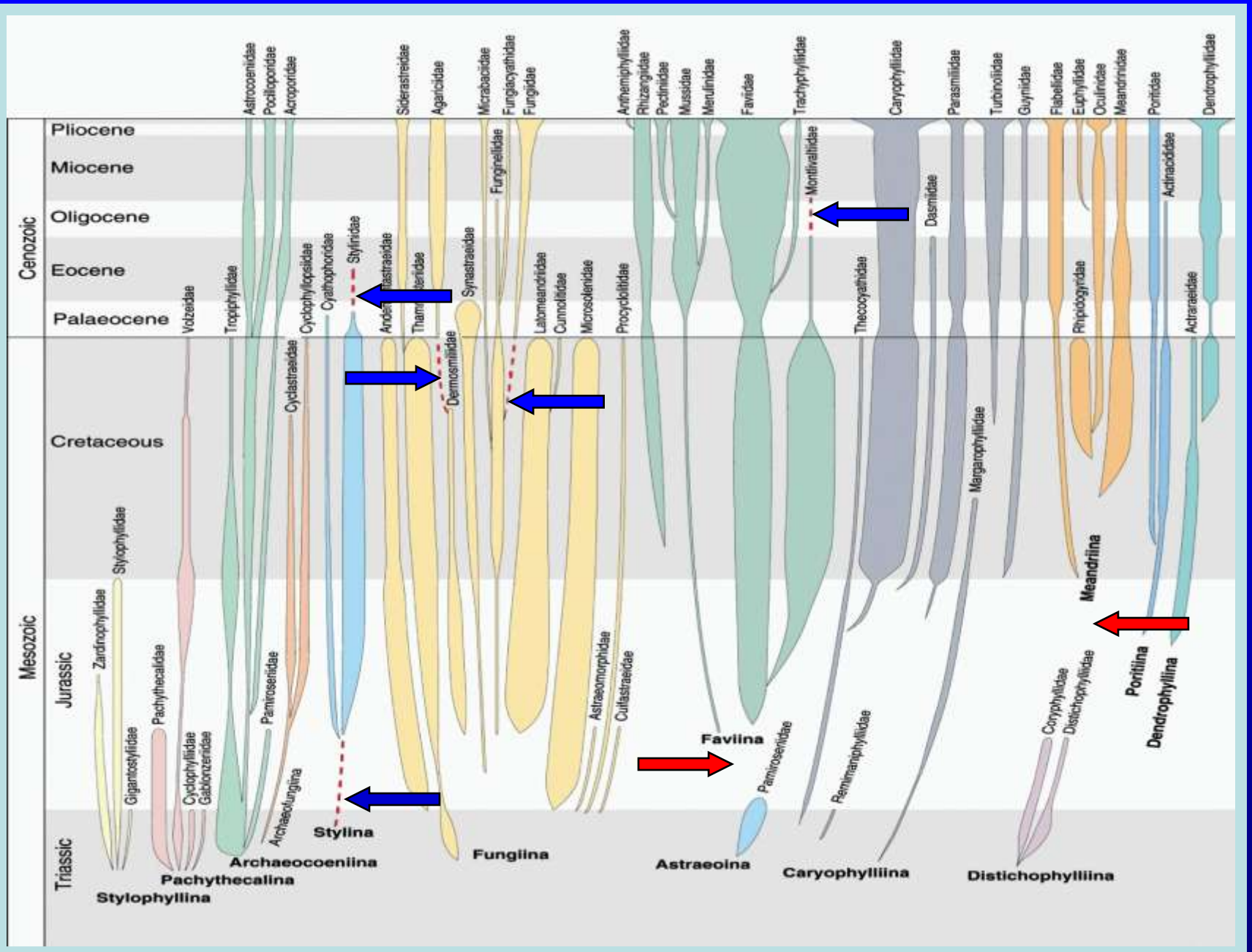





- Scleractinians originated 300 mya -- long before their initial appearance in the mid-Triassic
- 110-132 mya (Early Cretaceous) coinciding with high $CO_2$ levels and low Ca solubility, the calcified skeleton was lost but the “naked” anemone continued




Stanley & Fautin 2001 Science


Cenozoic
Mesozoic
Pliocene
Miocene
Oligocene
Eocene
Palaeocene
Cretaceous
Jurassic
Triassic
Astrocoeniidae
Pocilloporidae
Acroporidae
Siderastreidae
Agariciidae
Micrabaciidae
Fungiacyathidae
Fungiidae
Anthemiphyllidae
Rhizangiidae
Pectiniidae
Mussidae
Merulinidae
Faviidae
Trochyphyllidae
Caryophyllidae
Parasmiliidae
Turbinoliidae
Guyniidae
Flabellidae
Euphyllidae
Oculinidae
Meandriniidae
Poritidae
Dendrophyllidae
Volzeidae
Tropiphyllidae
Cyclophyllopsilidae
Cyathophoridae
Stylinidae
Andeastraeidae
Thamnasteriidae
Synastraeidae
Funginellidae
Latomeandriidae
Cunnolitidae
Microsolenidae
Procyclolitidae
Montlivaltiidae
Thecocyathidae
Dasmiidae
Margarophyllidae
Rhipidogyridae
Actinacididae
Actiraraeidae
Cyclastraeidae
Dermosmiliidae
Zardinophyllidae
Stylophyllidae
Gigantostylidae
Pachythecalidae
Cyclophyllidae
Gablonzeniidae
Pamiroseriidae
Archaeolungina
Astraeomorphidae
Cuifastraeidae
Parmiroseriidae
Remimantiphyllidae
Coryphyllidae
Distichophyllidae
Stylina
Archaeocoeniina
Pachythecalina
Stylophyllina
Fungiina
Faviina
Astraeoina
Caryophylliina
Meandriina
Poritiina
Dendrophyllina
Distichophylliina

Veron (1996)

# What caused Corals to go naked?

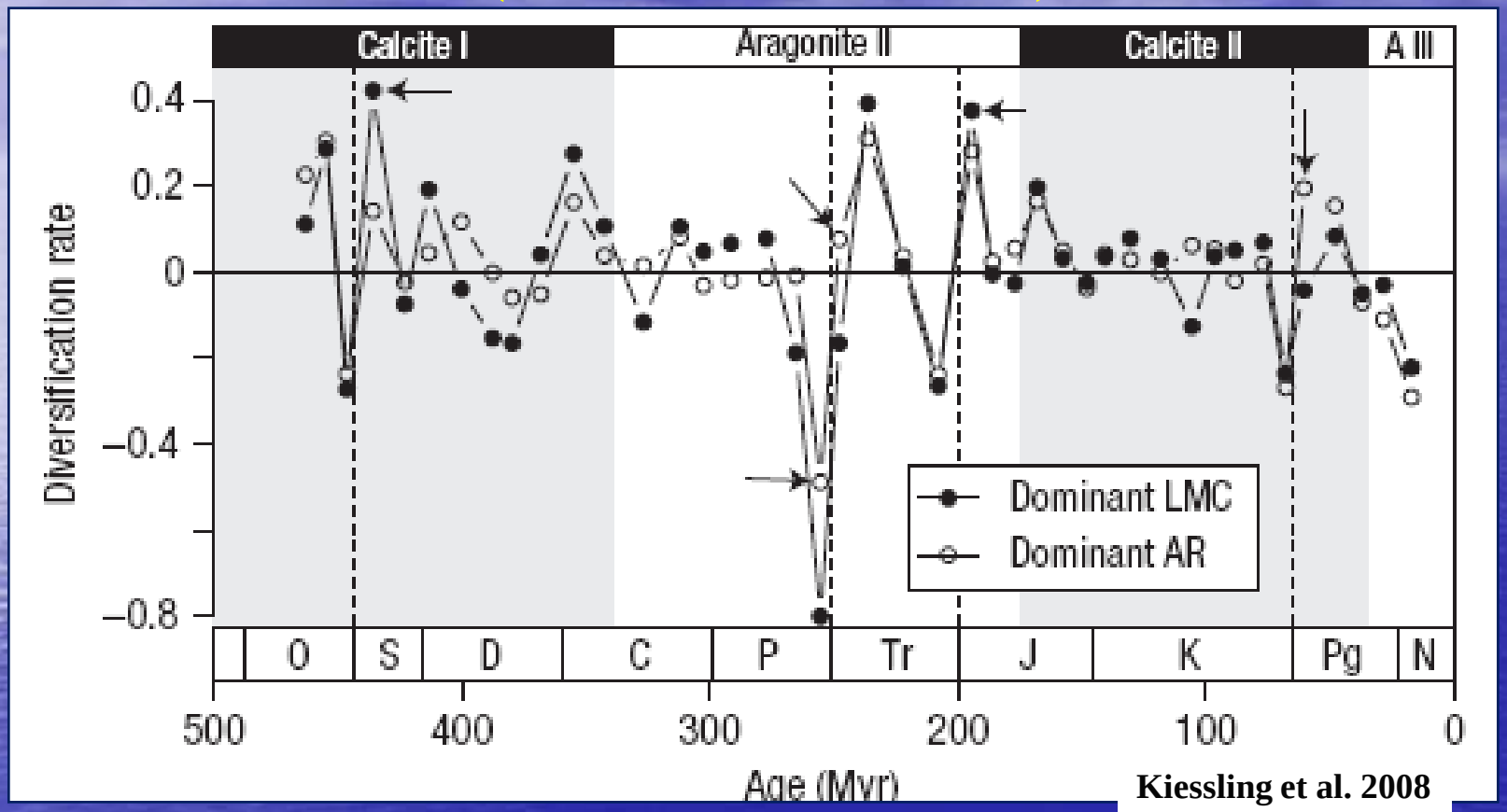
## Physiological responses to changing ocean chemistry

- Changing Ca/Mg in seawater?
- OR Increase in $pCO_2$ and solubility

Robert Nicholls

# Coral Diversification Rates

## (PaleoReefs Database)




Kiessling et al. 2008

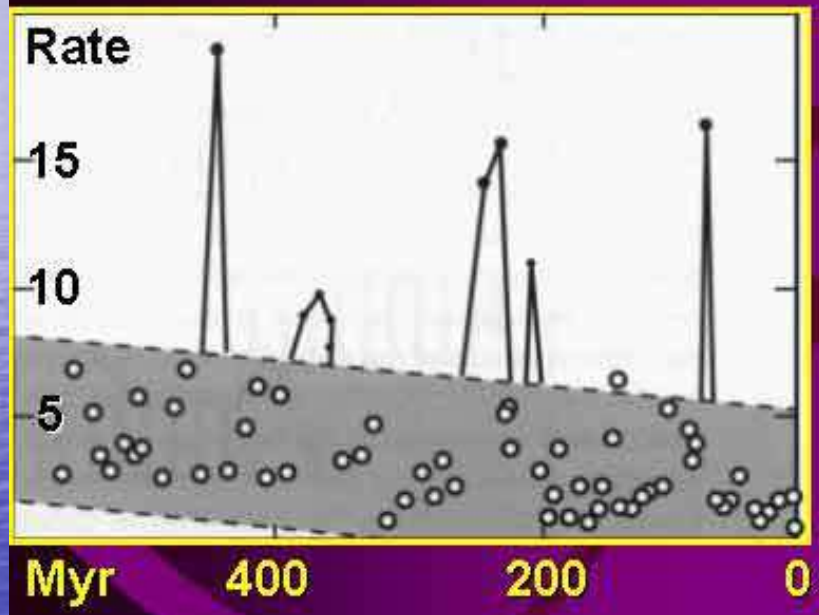
- **Mass extinctions (dashed lines) not associated with change in Ca/Mg ratios**

- **No evidence of reduced extinction rates or greater origination/diversification rates for aragonite corals than calcite corals**

# Mass Extinctions

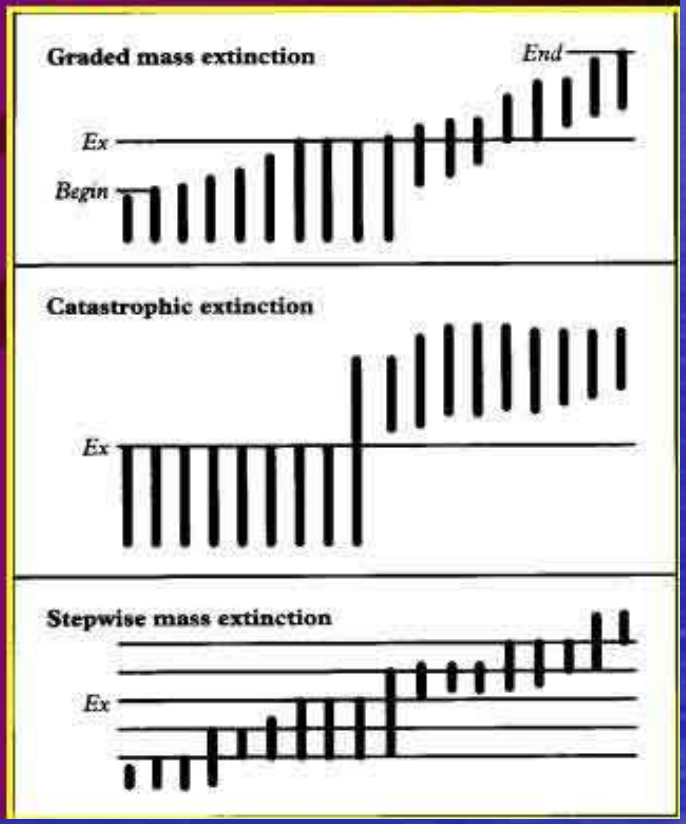
# Common characterisitics of biotic crises

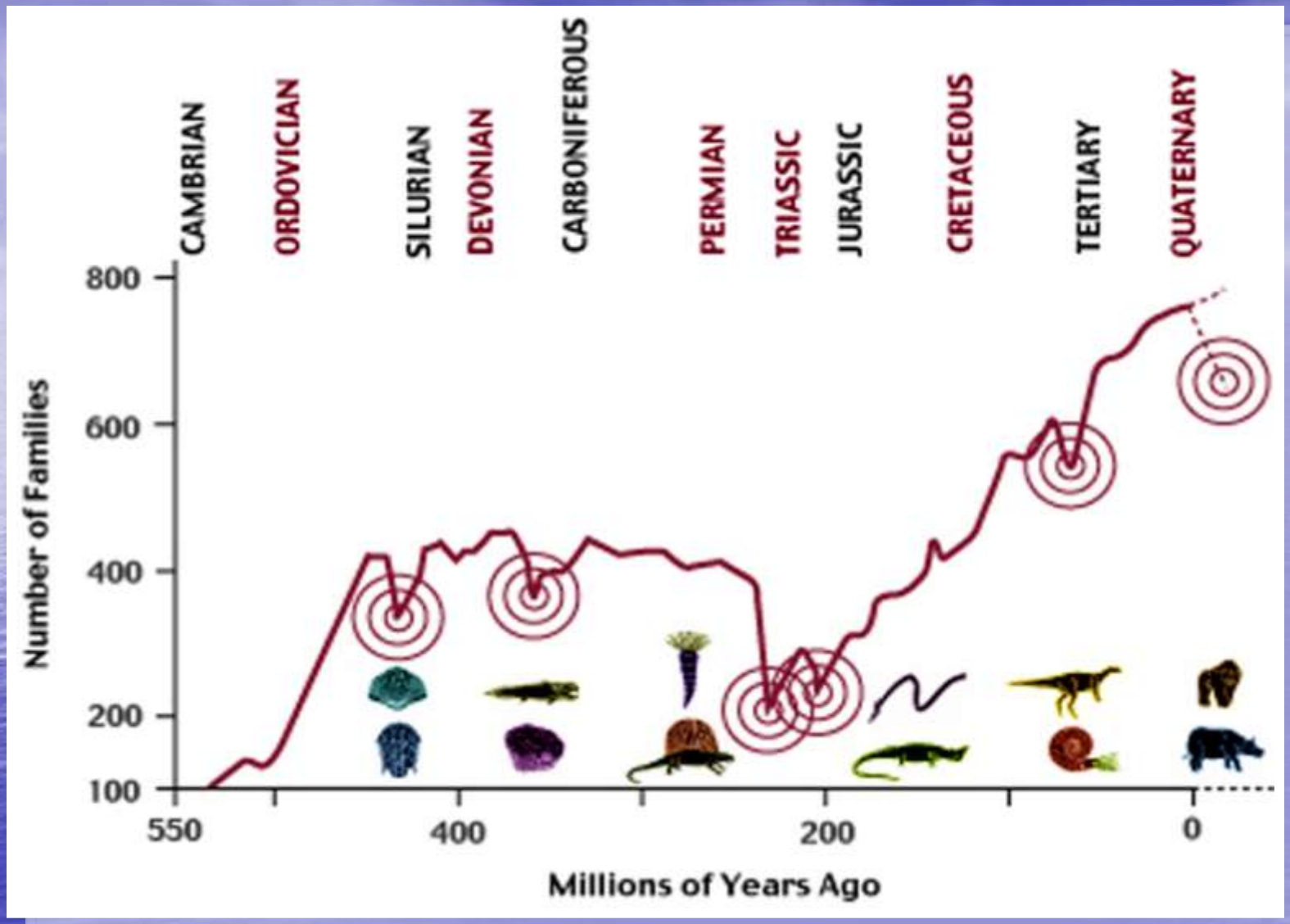
- rates exceed background extinction level
- extinction typically gradual or stepwise

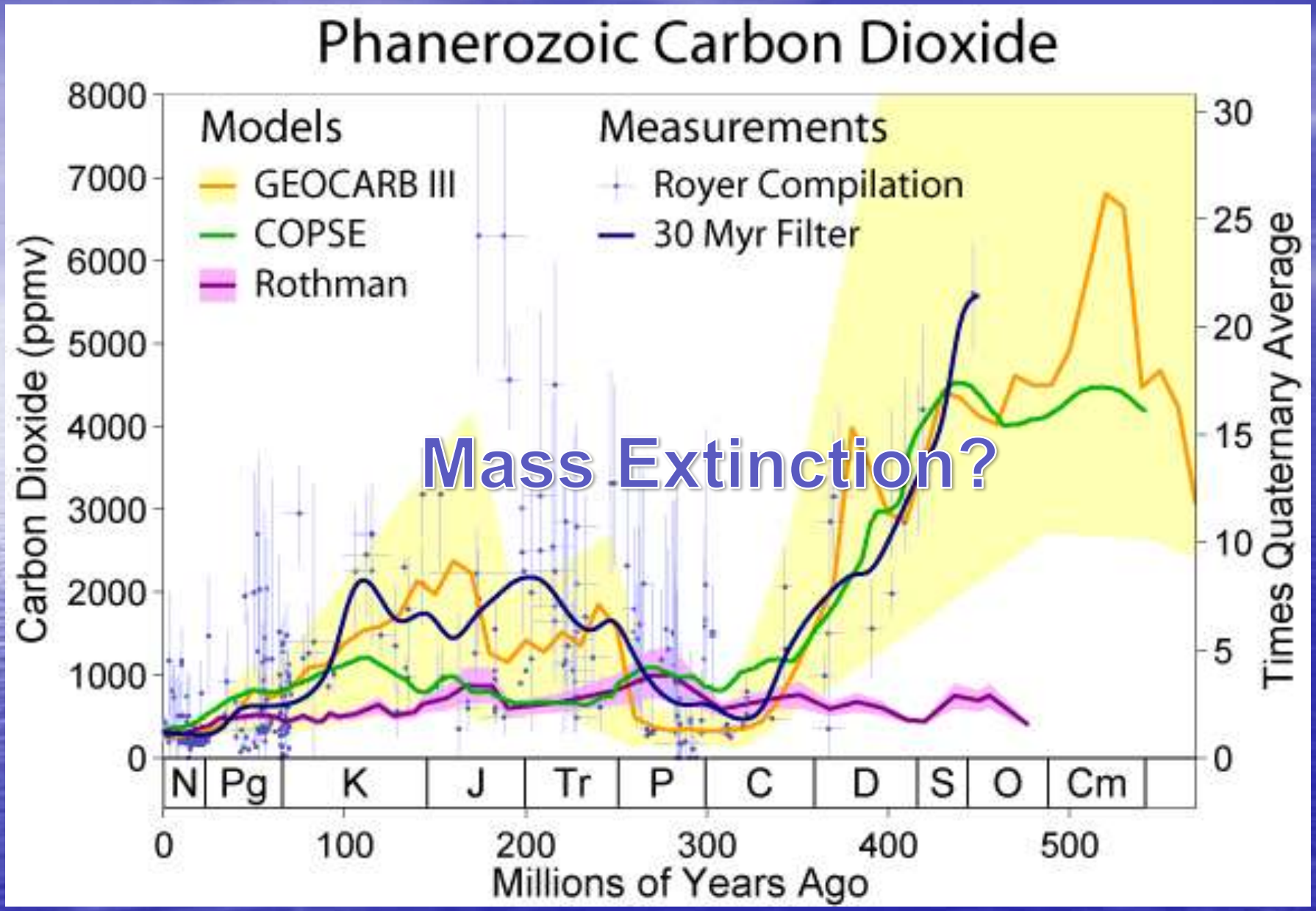



**Five events stand out**

Courtillot 1999



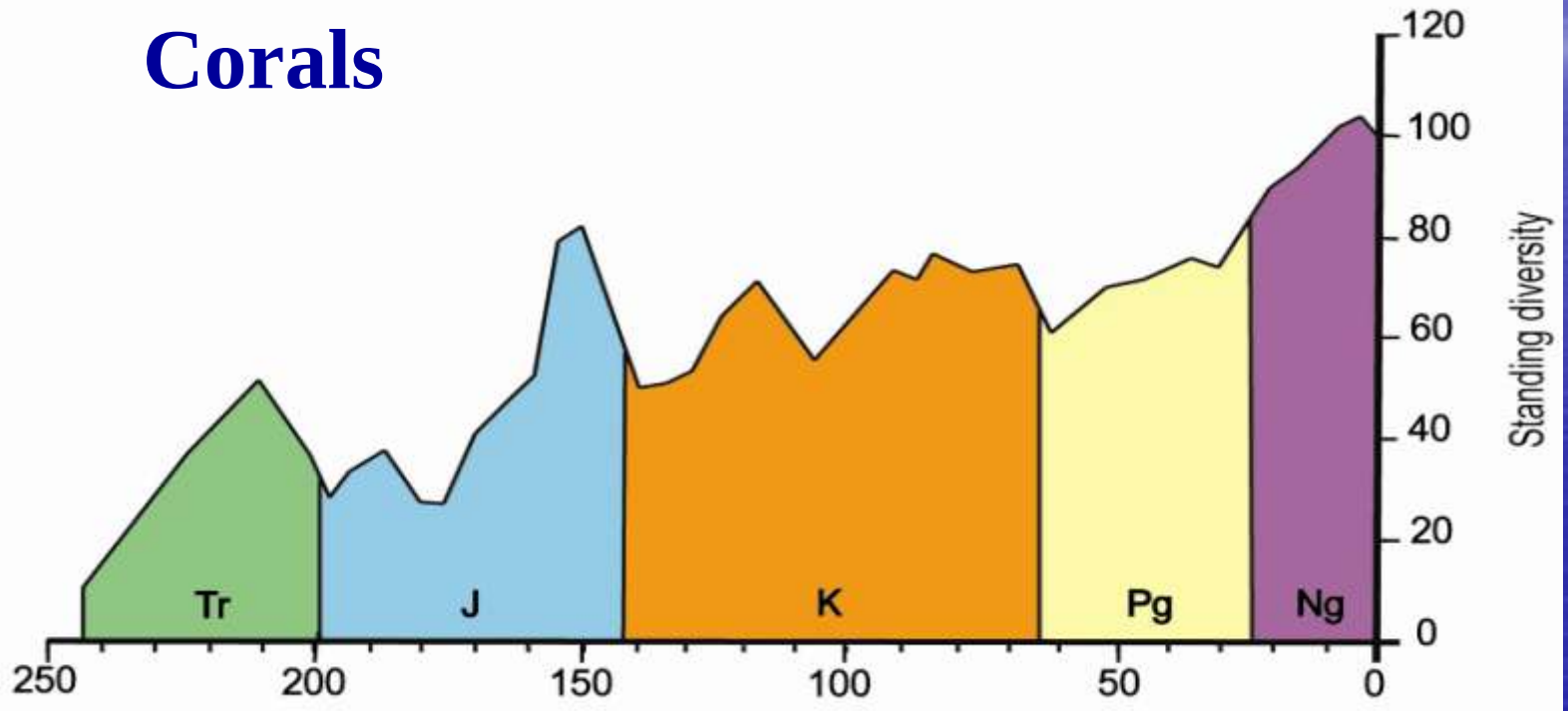

CAMBRIAN
ORDOVICIAN
SILURIAN
DEVONIAN
CARBONIFEROUS
PERMIAN
TRIASSIC
JURASSIC
CRETACEOUS
TERTIARY
QUATERNARY
800
600
400
200
100
Number of Families
550
400
200
0
Millions of Years Ago



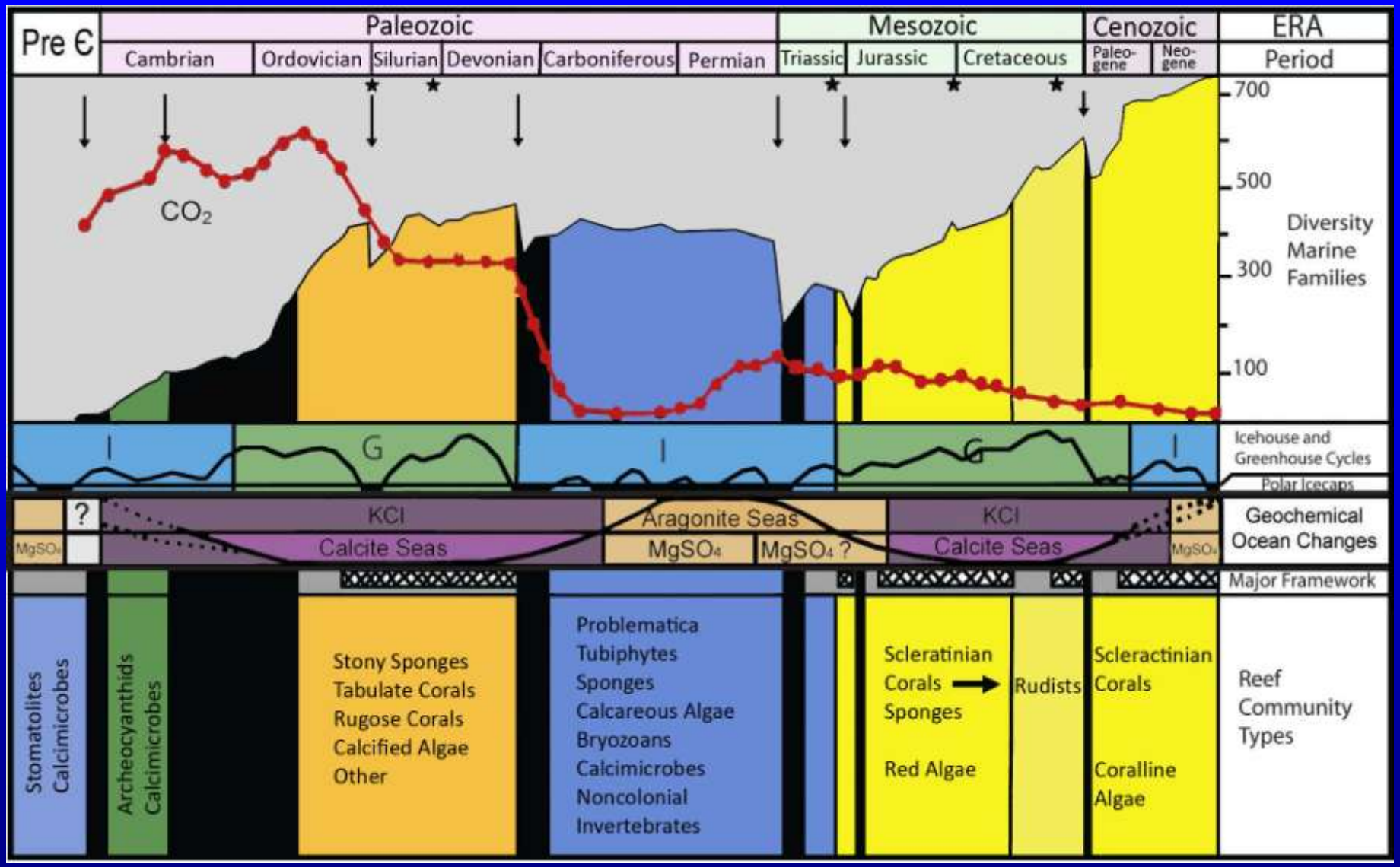

**GEOCARB III** (Berner and Kothavala 2001); **COPSE** (Bergmann et al. 2004); Rothman (2001); Royer et al. (2004).

**Robert A. Rohde Global Warming Art Project**

# Corals


Tr
J
K
Pg
Ng
250
200
150
100
50
0
120
100
80
60
40
20
0
Standing diversity


- Ocean cooling or warming
- Sunlight reduction
- Eutrophication of the sea
- Release of methane and other greenhouse gases
- Ocean acidification


Pre Є
Paleozoic
Mesozoic
Cenozoic
ERA
Cambrian
Ordovician
Silurian
Devonian
Carboniferous
Permian
Triassic
Jurassic
Cretaceous
Paleo-gene
Neo-gene
Period
CO2
700
500
300
100
Diversity Marine Families
I
G
I
G
I
Icehouse and Greenhouse Cycles
Polar Icecaps
?
KCl
Calcite Seas
Aragonite Seas
MgSO4
MgSO4 ?
KCl
Calcite Seas
MgSO4
MgSO4
Geochemical Ocean Changes
Major Framework
Stomatolites Calcimicrobes
Archeocyanthids Calcimicrobes
Stony Sponges
Tabulate Corals
Rugose Corals
Calcified Algae
Other
Problematica
Tubiphytes
Sponges
Calcareous Algae
Bryozoans
Calcimicrobes
Noncolonial Invertebrates
Scleratinian Corals
Sponges
Red Algae
Rudists
Scleractinian Corals
Coralline Algae
Reef Community Types

# Extinction Patterns For Reefs

- Mass extinction and rapid reef collapse
- Global perturbation of oceans involve events of acidification
- Loss of calcifiers (corals)
- Reefs eclipse (1-10 Ma) – Delayed recovery

# Physio-Chemical Consequences

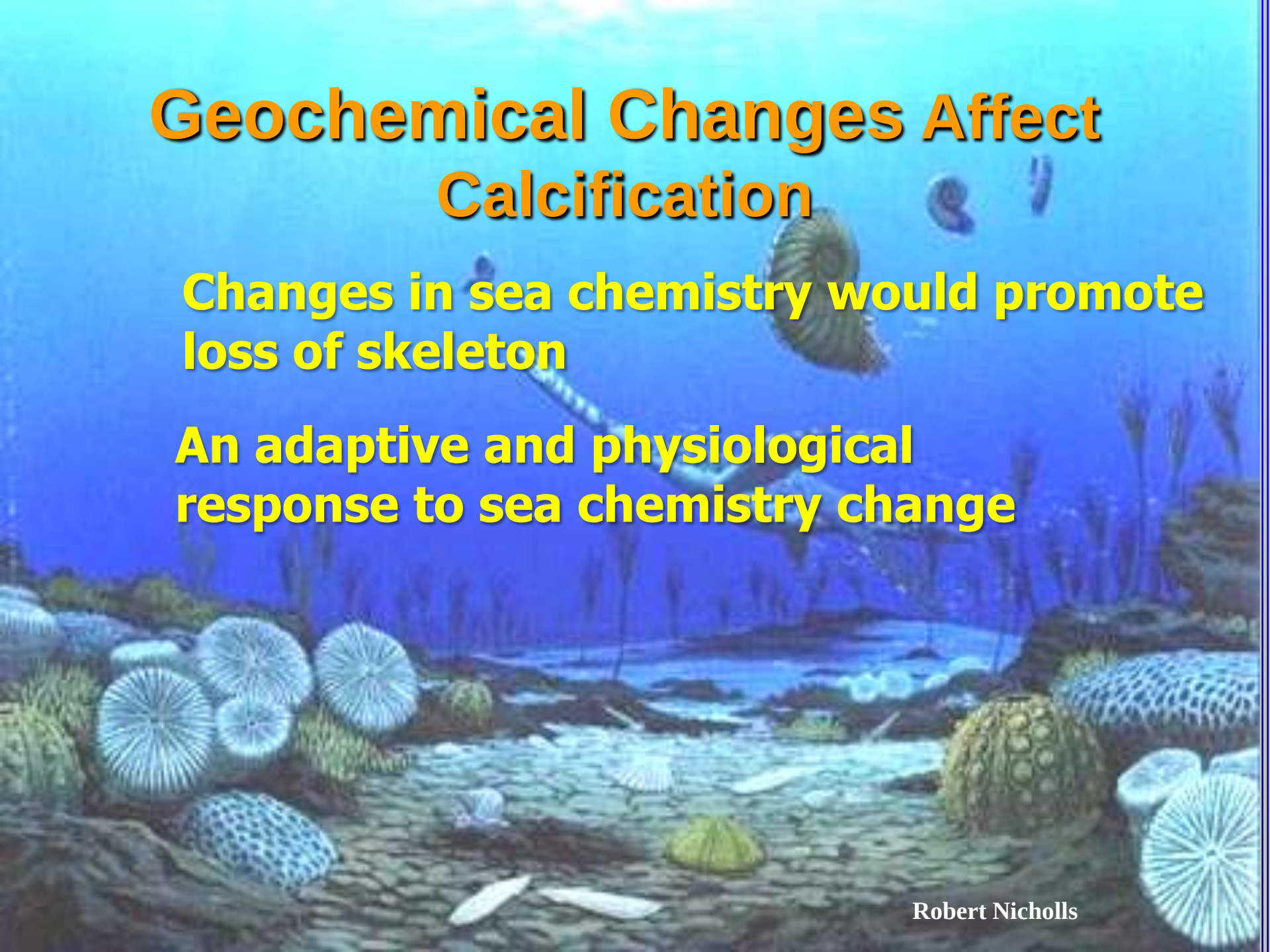
- Increase in $pCO_2$
- Leading to Acidification of seawater

Robert Nicholls

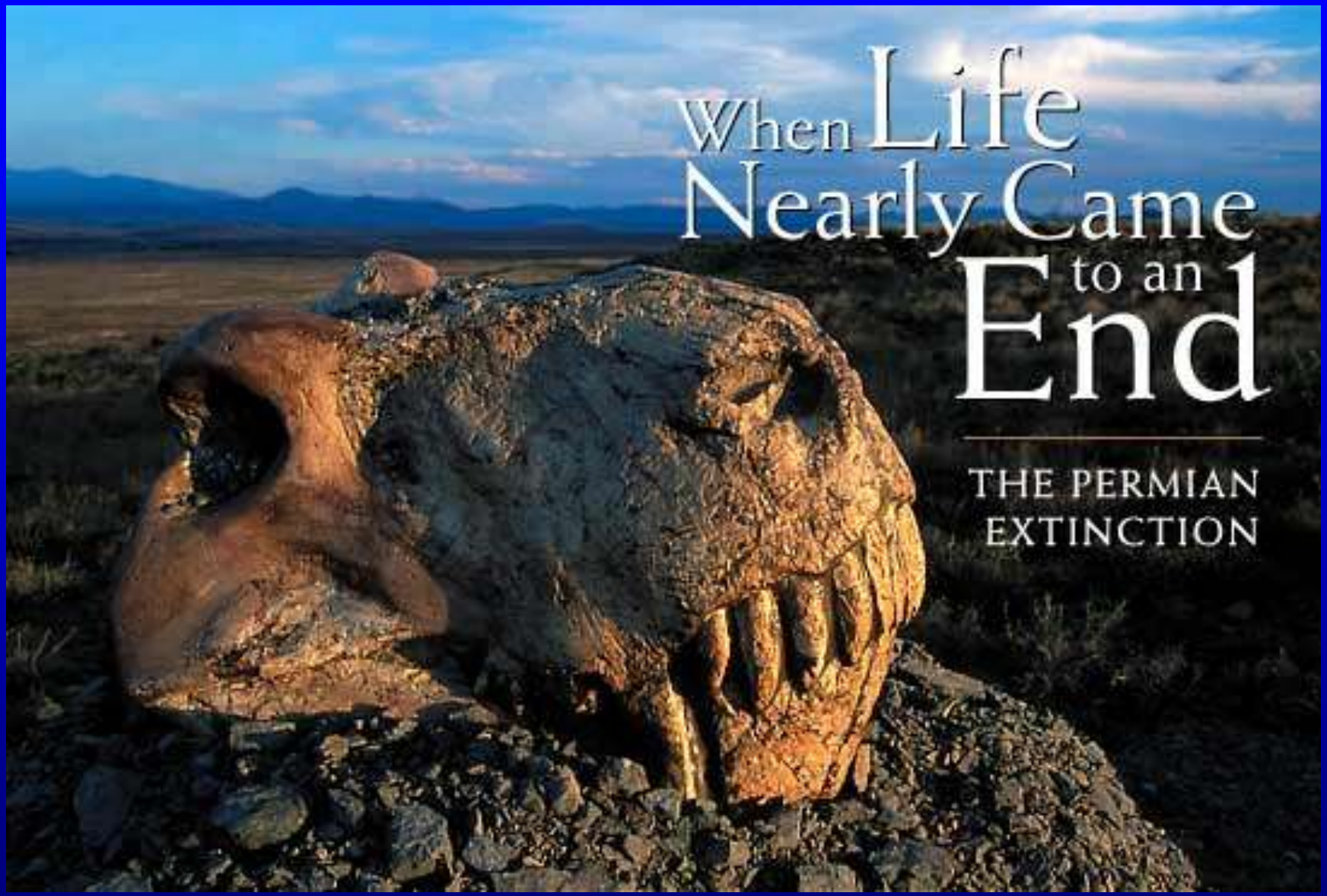
# Geochemical Changes Affect Calcification

Changes in sea chemistry would promote loss of skeleton

An adaptive and physiological response to sea chemistry change



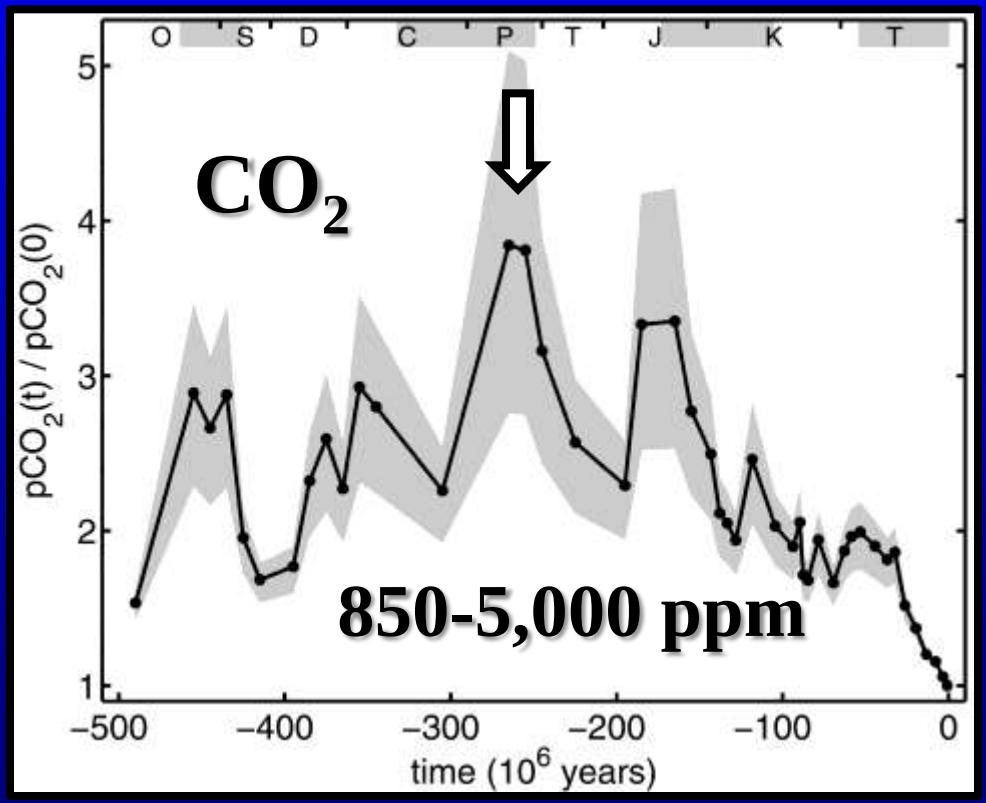
Robert Nicholls

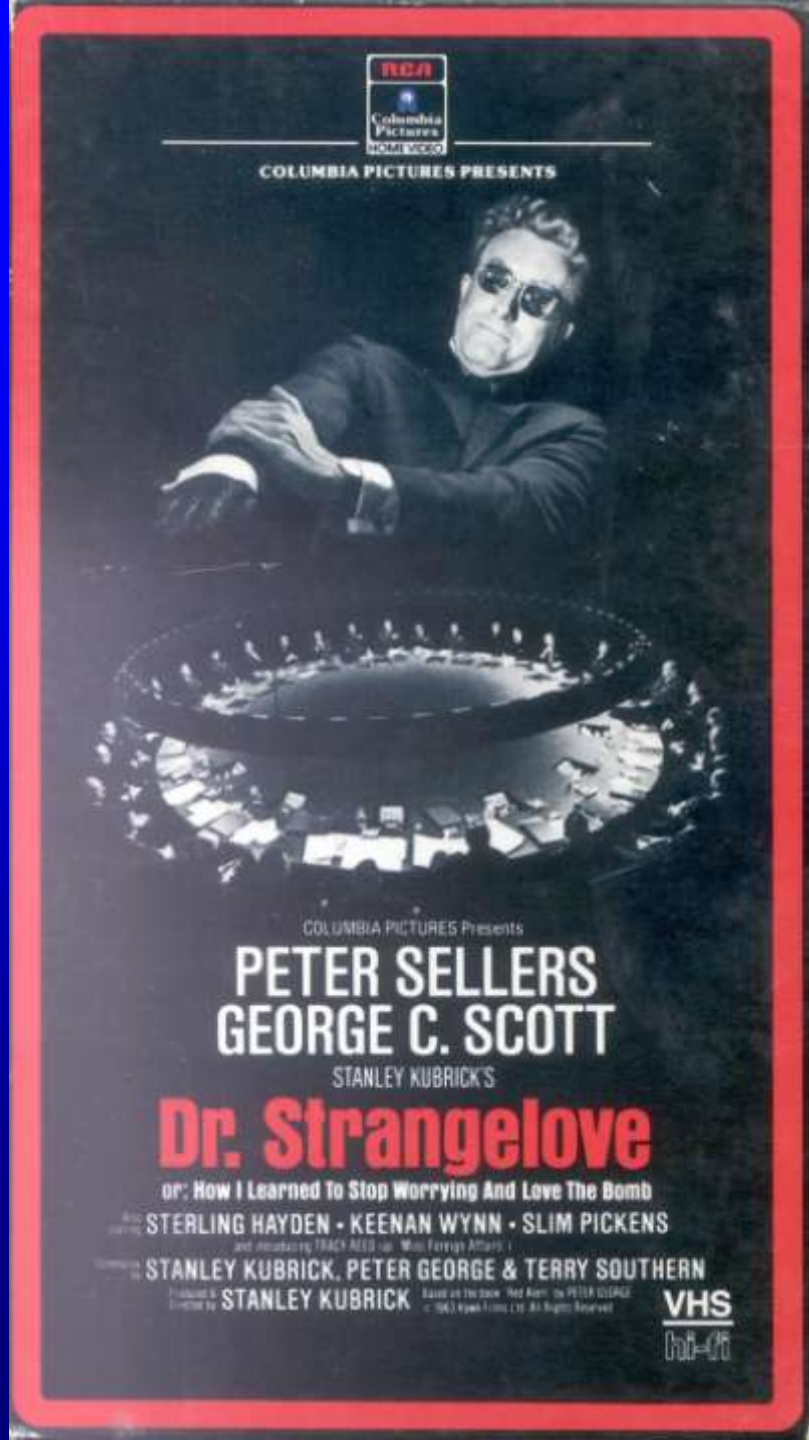

When Life Nearly Came to an End
THE PERMIAN EXTINCTION

# "Strangelove Ocean"

**End Permian Mass Extinction**

**Perturbation of ocean chemistry after the mass extinction**



# END –TRIASSIC EXTINCTION

**N. Jb. Geol. Paläont. Abh.**
2008, vol. 249/1, p. 119–127, Stuttgart, July 2008, published online 2008

## Catastrophic ocean acidification at the Triassic-Jurassic boundary

**Michael Hautmann,** Zürich, **Michael J. Benton,** Bristol, and **Adam Tomašových,** Chicago

With 3 figures

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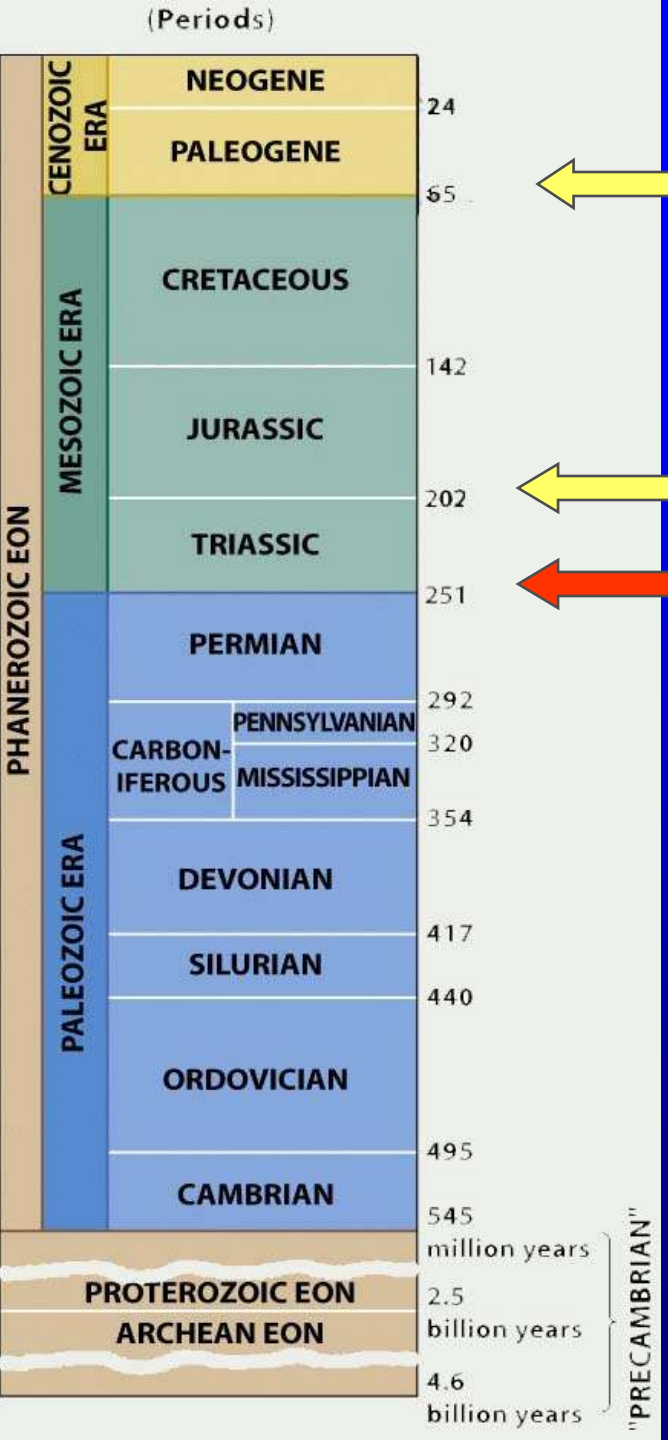
HAUTMANN, M., BENTON, M. J. & TOMAŠOVÝCH, A. (2008): Catastrophic ocean acidification at the Triassic-Jurassic boundary. – N. Jb. Geol. Paläont. Abh., **249**: 119–127; Stuttgart.

**Abstract:** Palaeobotanical and geochemical evidence indicate a sudden rise in atmospheric carbon dioxide ($CO_2$) across the Triassic-Jurassic boundary, probably reflecting the combined effect of extensive volcanic degassing and thermal dissociation of marine gas hydrates. Using carbon isotopes as a geochemical marker, we found that the onset of the $CO_2$ emissions coincided with an interruption of carbonate sedimentation in palaeogeographically distant regions, suggesting that hydrolysis of $CO_2$ led to a short but substantial decrease of seawater pH that slowed down or inhibited precipitation of calcium carbonate minerals. The cessation of carbonate sedimentation correlates with a major marine extinction event, which especially affected organisms with aragonitic or high-Mg calcitic skeletons and little physiological control of biocalcification. These findings strengthen current concerns that ocean acidification from industrial $CO_2$ release threatens biotopes that are dominated by such organisms, in particular tropical reef systems.




# Ocean Acidification

**K-T extinction & reef collapse**

**1000-3000 ppm $CO_2$**

**Mega-Reef Greenhouse -- Jurassic-Cretaceous**

**End-Triassic extinction & reef collapse**

**600-2400 ppm $CO_2$**

*** Permo-Triassic extinction**

**850-5,000 ppm $CO_2$**

**May accounts for the unexplained delayed recovery of reefs**

# Scleractinian Coral Species Survive and Recover from Decalcification

Maoz Fine[1,3]* and Dan Tchernov[2,3]

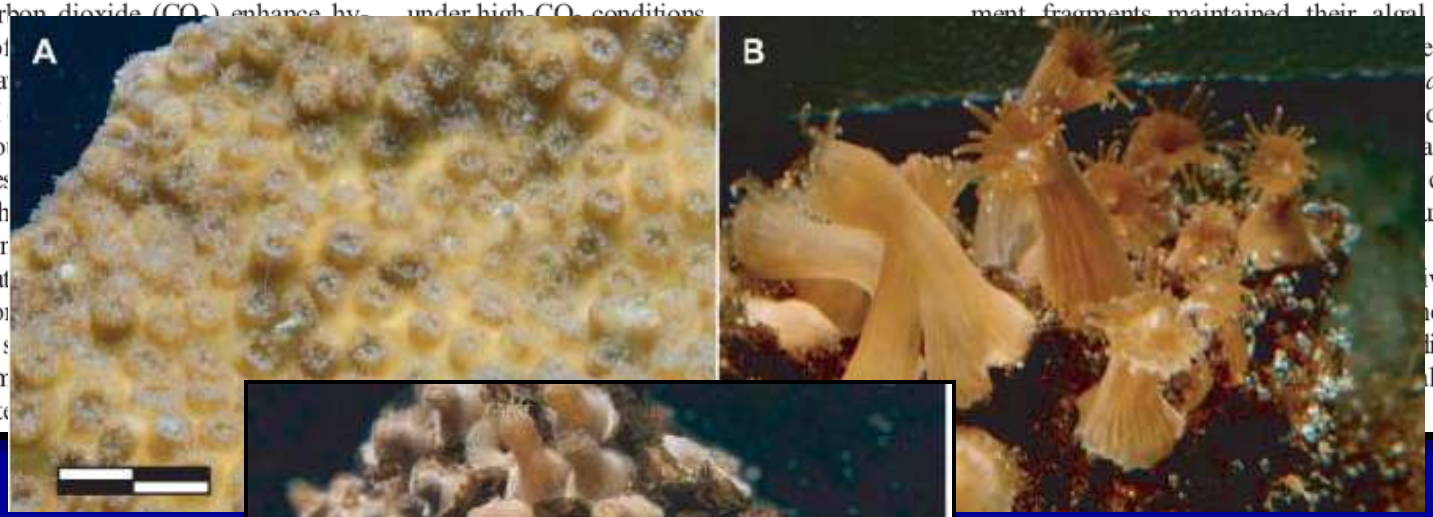
Increasing global concentrations of atmospheric carbon dioxide ($CO_2$) enhance hydrolysis of decreasing sea caused the pH 8.3) to be abo industrial times estimated furth units over the r

Increased at bonate ion co decreases the s the principal r together with t

from net accumulation at present to net loss under high-$CO_2$ conditions

photons $m^{-2}$ $s^{-1}$). After 1 month in acidic conditions, morphological changes were seen, initially polyp elongation (Fig. 1B), followed by dissociation of the colony form and complete skeleton dissolution. Surprisingly, the polyps remained attached to the undissolved hard rocky substrate (Fig. 1C).

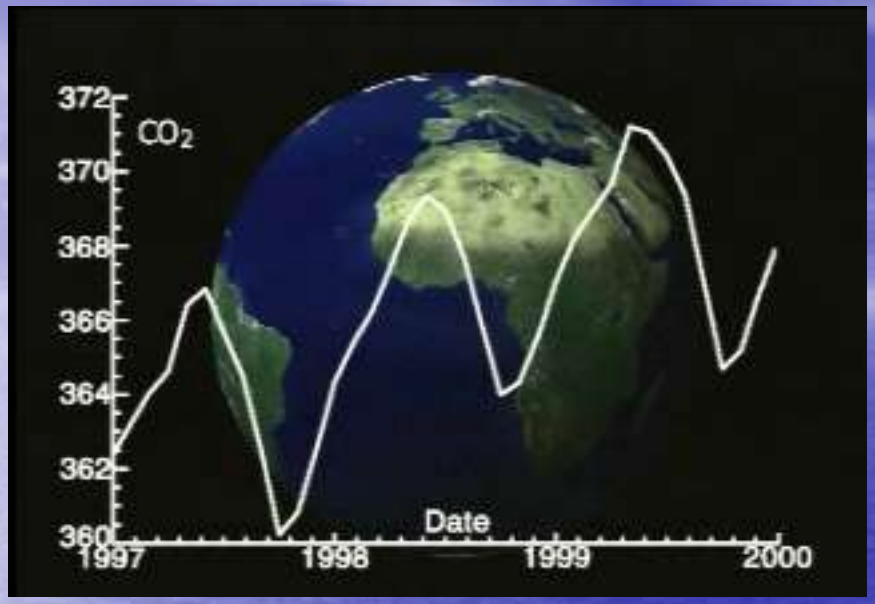
The biomass of the solitary polyps under acidic conditions was three times as high as the biomass of polyps in the control colonies that continued to calcify and grow. Control and treatment fragments maintained their algal sym- ept for *a* that during ameto- corals ummer ived to onths, litions, lcified in the




March 30, 2007


**Some corals may survive acidification caused by rising CO2 levels**
**mongabay.com**
**March 29, 2007**

Several studies have shown that increased atmospheric carbon dioxide levels are acidifying the world's oceans. This is significant for coral reefs because acidification strips carbonate ions from seawater, making it more difficult for corals to build the calcium carbonate skeletons that serve as their structural basis. Research has shown that many species of coral, as well as other marine microorganisms, fare quite poorly under the increasingly acidic conditions forecast by some models. However, the news may not be bad for all types of corals. A study published in the March 30 issue of the journal *Science*, suggests that some corals may weather acidification better than others.




North Wales Chronicle, 26th January, 2006, p 7

# Greenhouse effect 'just a natural cycle'

REGARDING the letter A Call To Support The Windfarms of January 5.

Climate change is happening as part of a natural cycle change, that happens about every 100,000 years or so, and at this moment in time we are in about the 75,000th year of that cycle.

I do agree that emissions of $CO_2$ from cars, industry, volcanoes, the earth itself and oxygen-breathing mammals, ourselves, do change.

forget the world ng at an alarm- and consuming xygen from the ere than our s did thousands of years ago.

Wind power has now been proven NOT to cut $CO_2$ (greenhouse gases) by the over-stated amounts put out by wind contractors and the like, by as much as 50 per cent (fact).

Both the German and Dutch governments and now ours are stating just that, in fact they say by putting modern filtering on the existing generators, this would be cheaper and the same effect can be achieved.

Reading the Financial Mail today, it states that the French and other Europeans are willing to support the financing and the building of new nuclear high pressure water reactors, these to replace our old gas/coal and nuclear generators before 2020, they will take ten years to build.

This government will be looking at this possibility.

On the visibility aspect, they are visible, how often do we get hazy or misty days, not that many, so asks the question, what are the Gwynt y Mor turbines and the others going to look like, not only from Llandudno, east Anglesey, the north-east coast and the Wirral?

I hate to think.

It has been stated that if you wish to sell your home with these wind-farms in view it can make a difference to the price of that dwelling (Sustainable Development Commission).

Most of the visitors on Anglesey see the wind-farms as a blot on our landscape, and only view them as a curiosity.

I do not in any way dislike or condemn the use of alternatives as a way of producing power, we need them, but I wish more thought, true consultation and better planning would take place, especially in the siting and management of these alternatives.

This could put this well-written subject to bed once and for all.

**Name and address supplied**

**OCEAN ACIDIFICATION**
**NOTHING TO WORRY ABOUT**

Deep Sea News
The latest news on Earth's largest environment

# The naked coral hypothesis: a cause for optimism

**May 03, 2008**

Corals are tougher than we give them credit for. They survived climate change before- perhaps in a different form, a polypoid form lacking calcite called "the naked coral" (Stanley and Fautin 2001). Rugose corals thrived and developed during Paleozoic, but became extinct in the Permian. One of the primary hypotheses regarding the mass extinction of rugose corals is that increased levels of CO2 in the atmosphere resulted in reduced pH of seawater that altered the ability of corals to form their calcitic skeleton.

The threat of "ocean acidification" has also been invoked recently, but the phylogeny of corals has been largely overlooked. Laboratory research determined at least five species of corals can survive periods of low pH. They transform into a gelatinous mode akin to their conphyletic sea anemones, even maintaining their ability to reproduce and regrow skeletons as pH rises (Fine and Tchernov 2007). This supports the "naked coral" hypothesis. The hypothesis has been used to explain the sudden reappearance of Scleractinian corals in the Middle Triassic, when ocean conditions returned to normal, after corals were absent from the fossil record for millions of years. They may have survived that time in a gelatinous state. its seems far fetched, but coral reefs have survived millions of years of sea level change. They've weathered hurricanes, monsoons, brine seeps, geological faults, and sedimentation from natural changes in riverine output and direction. They've been around a long time.


Ocean Warming
IS A HOAX!
CLIMATE EXPERT RUSH LIMBAUGH
AT THE NORTH POLE THIS SUMMER
(The North Pole could be ice free for the first time this summer
according to the US National Snow and Ice Data Center)


"The world without corals is like a Van Gogh painting without color"
Joan Kleypas

# FUTURE RESEARCH

- Can predicted ocean acidification result in the dissolution of reef corals?
- Do dramatic increases in $pCO_2$ correlate with disappearance of ancient reefs?
- The "Naked Coral" hypothesis: more studies needed on physio-biochemistry of the coral skeleton in response to high $CO_2$


George D. Stanley, Jr.
University of Montana
george.stanley@umontana.edu