A multidisciplinary approach to investigating the scleractinian coral response to ocean acidification

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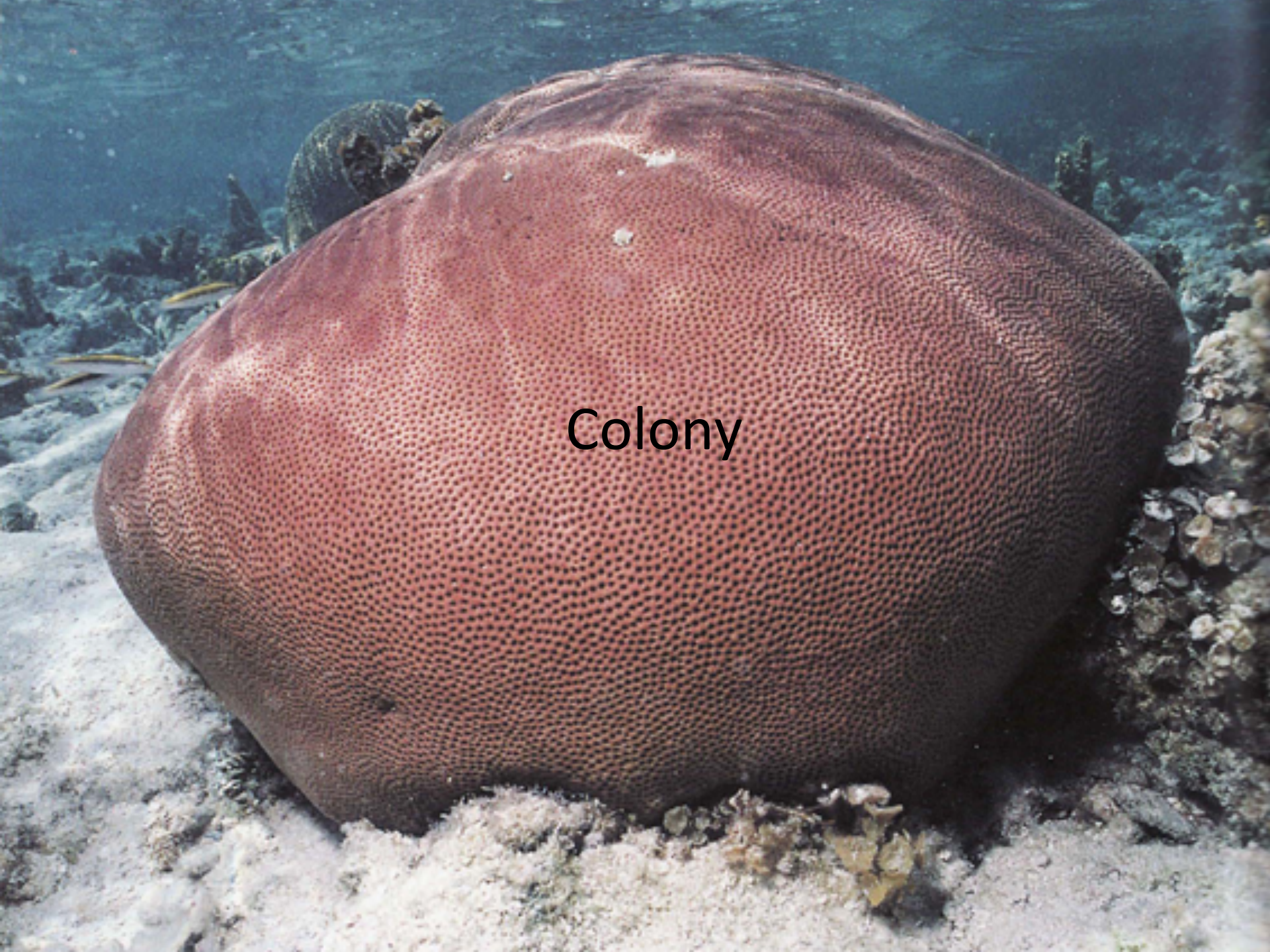
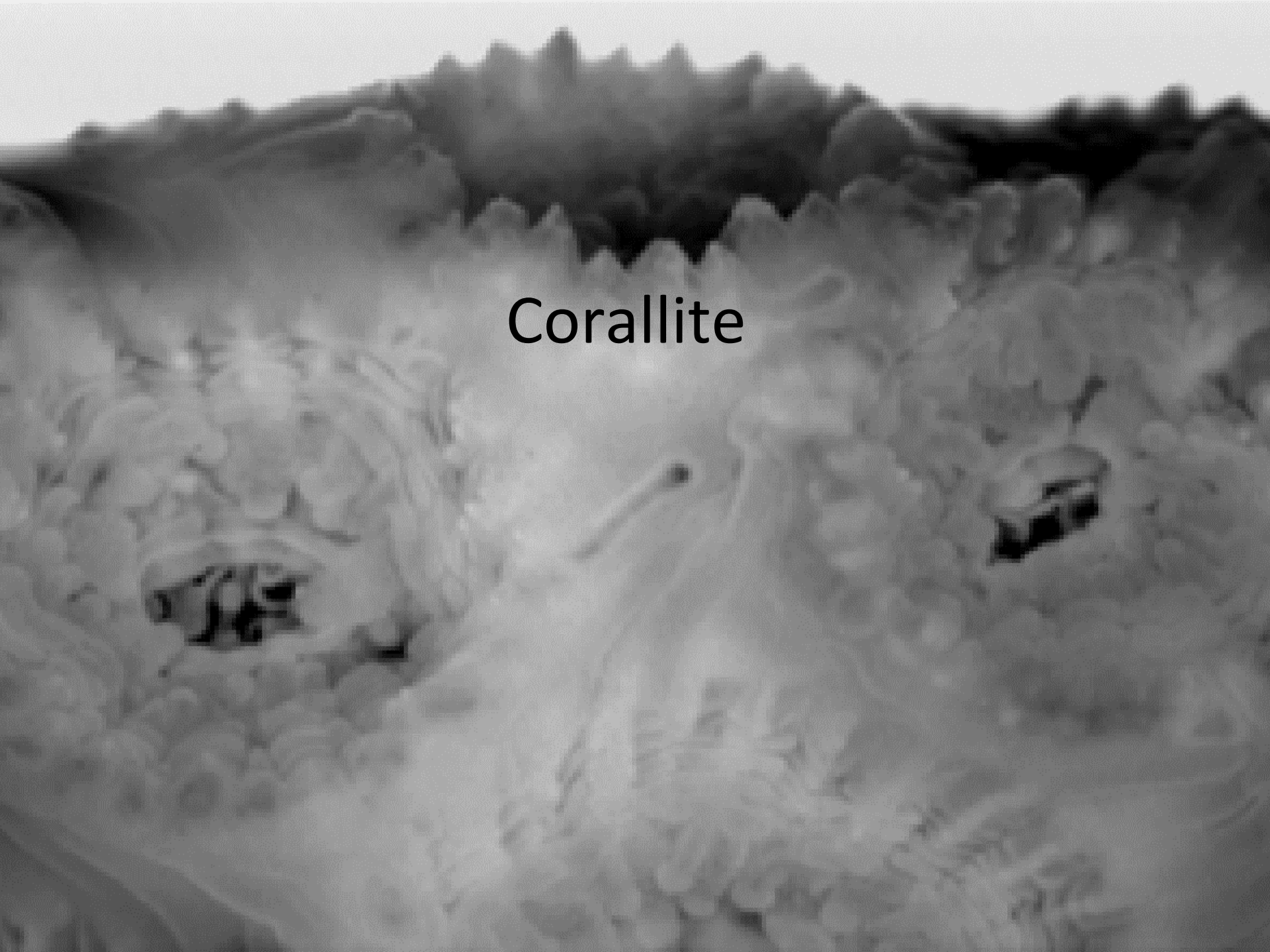
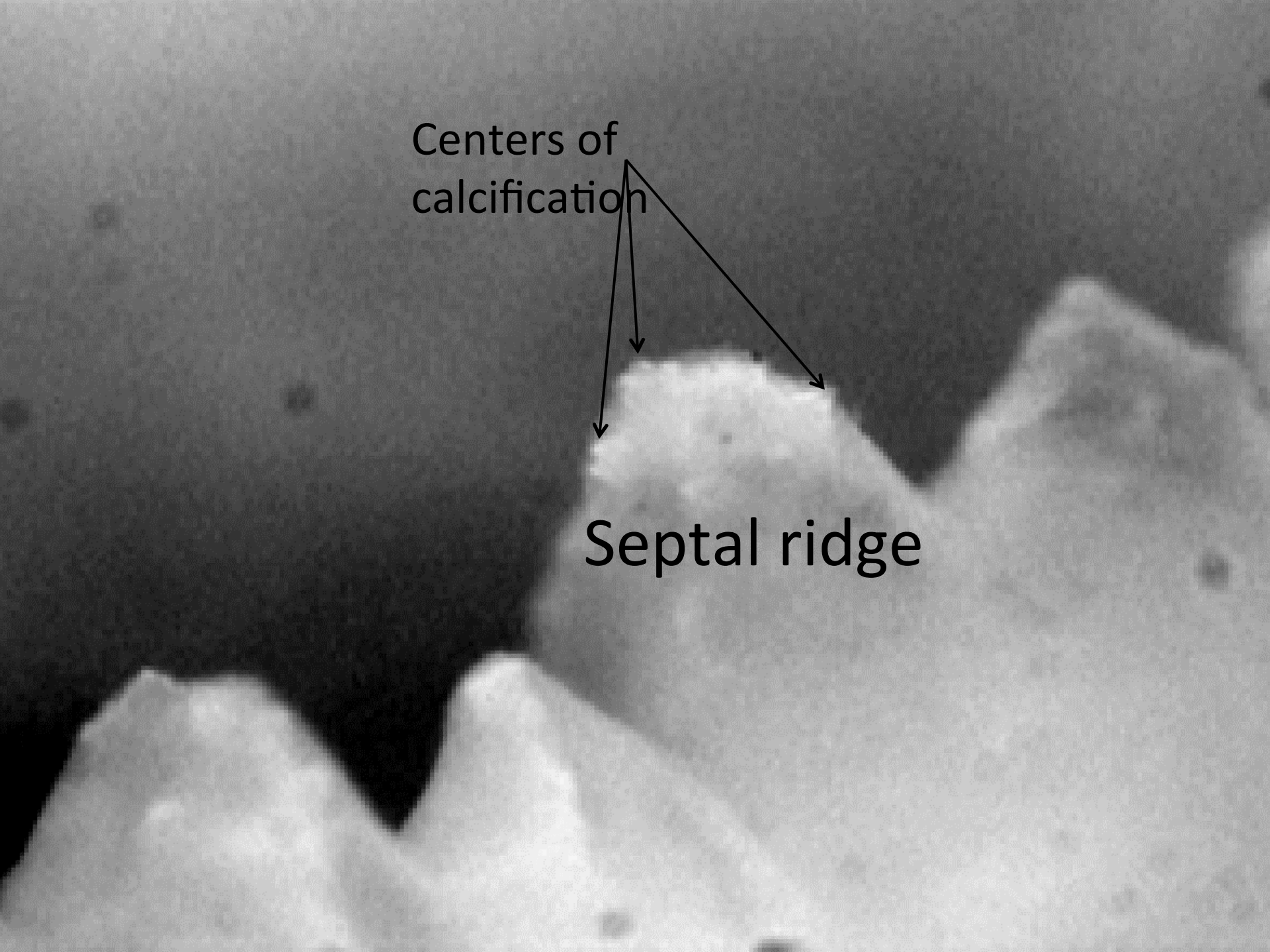
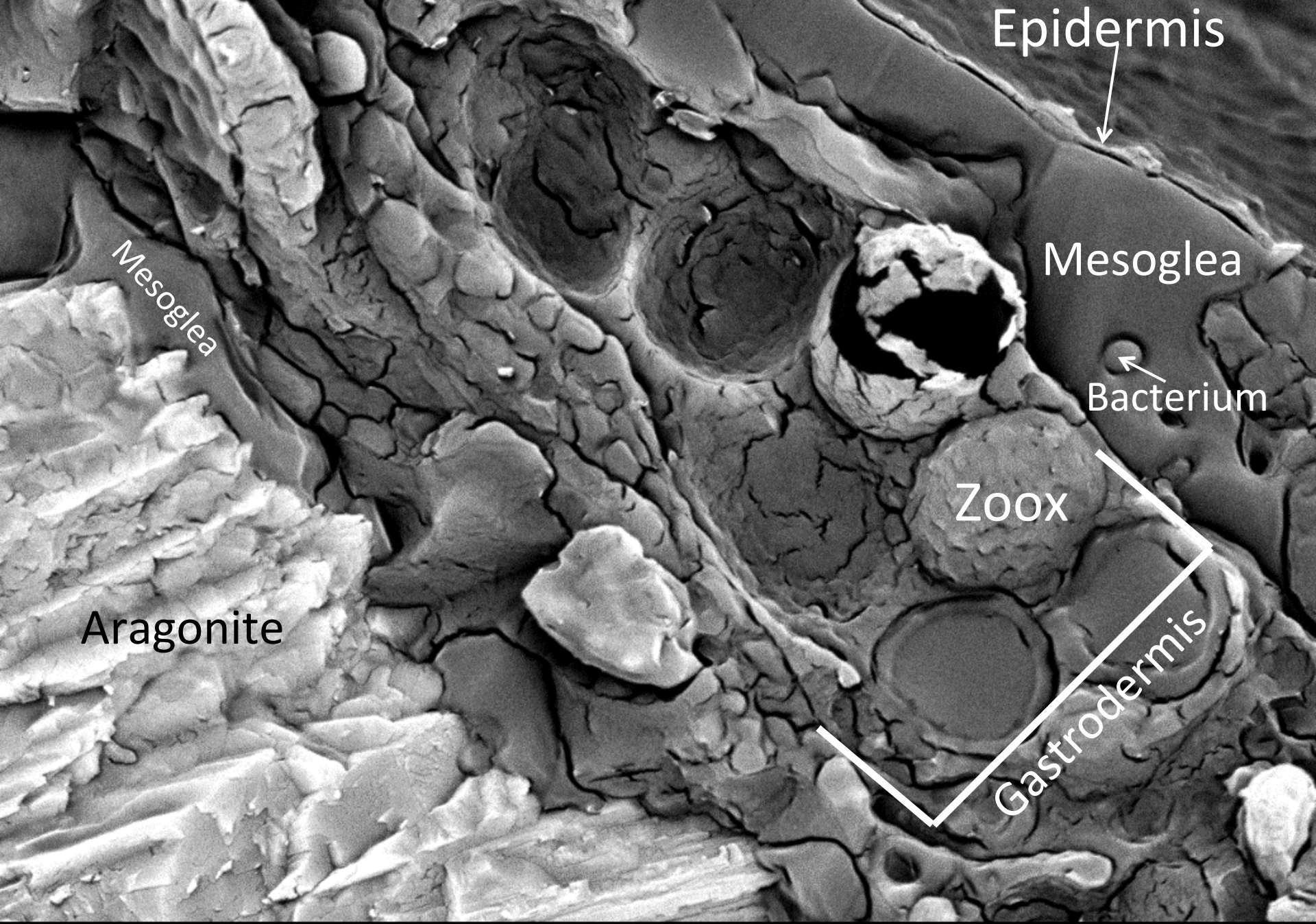
Northeastern University

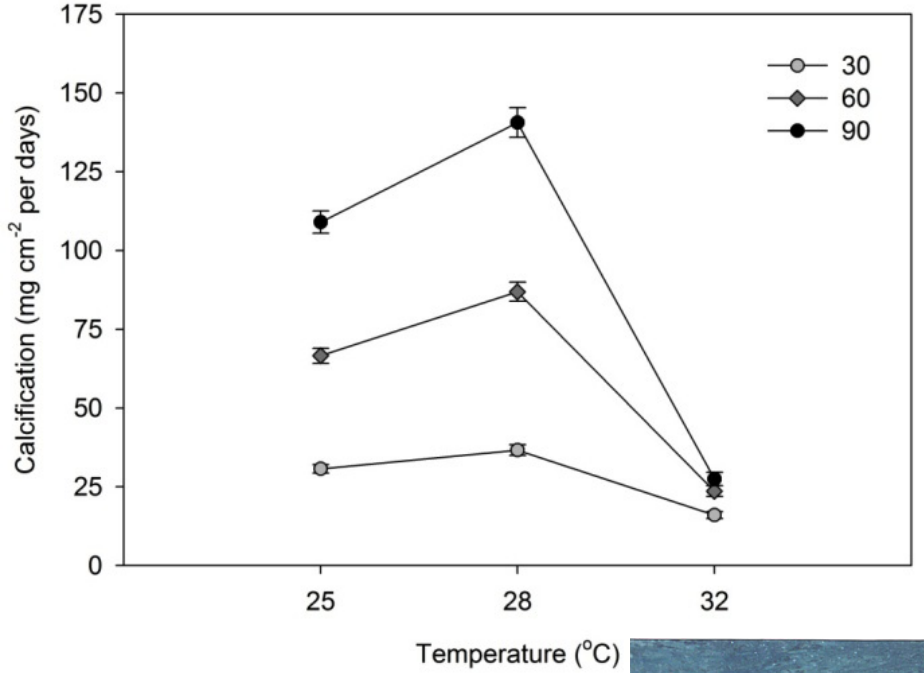

Colony

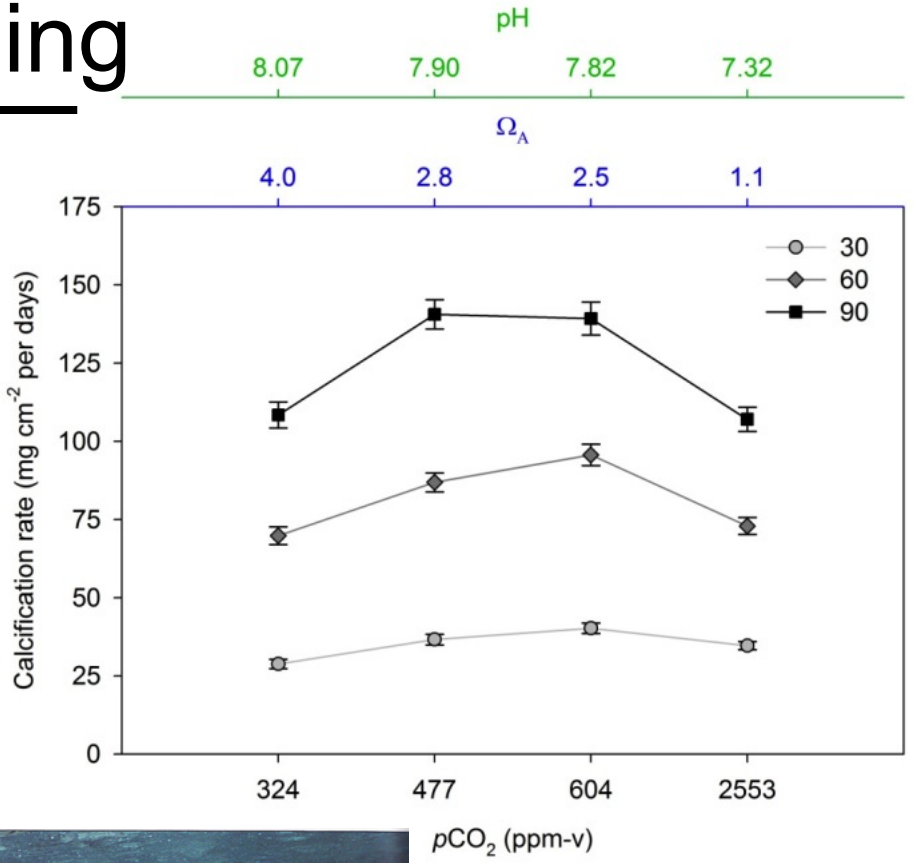

Corallite


Centers of calcification
Septal ridge


Epidermis
Mesoglea
Mesoglea
Bacterium
Zoox
Aragonite
Gastrodermis
1µm
x6,000
10.0kV BED-C
SEM
WD 9.7mm

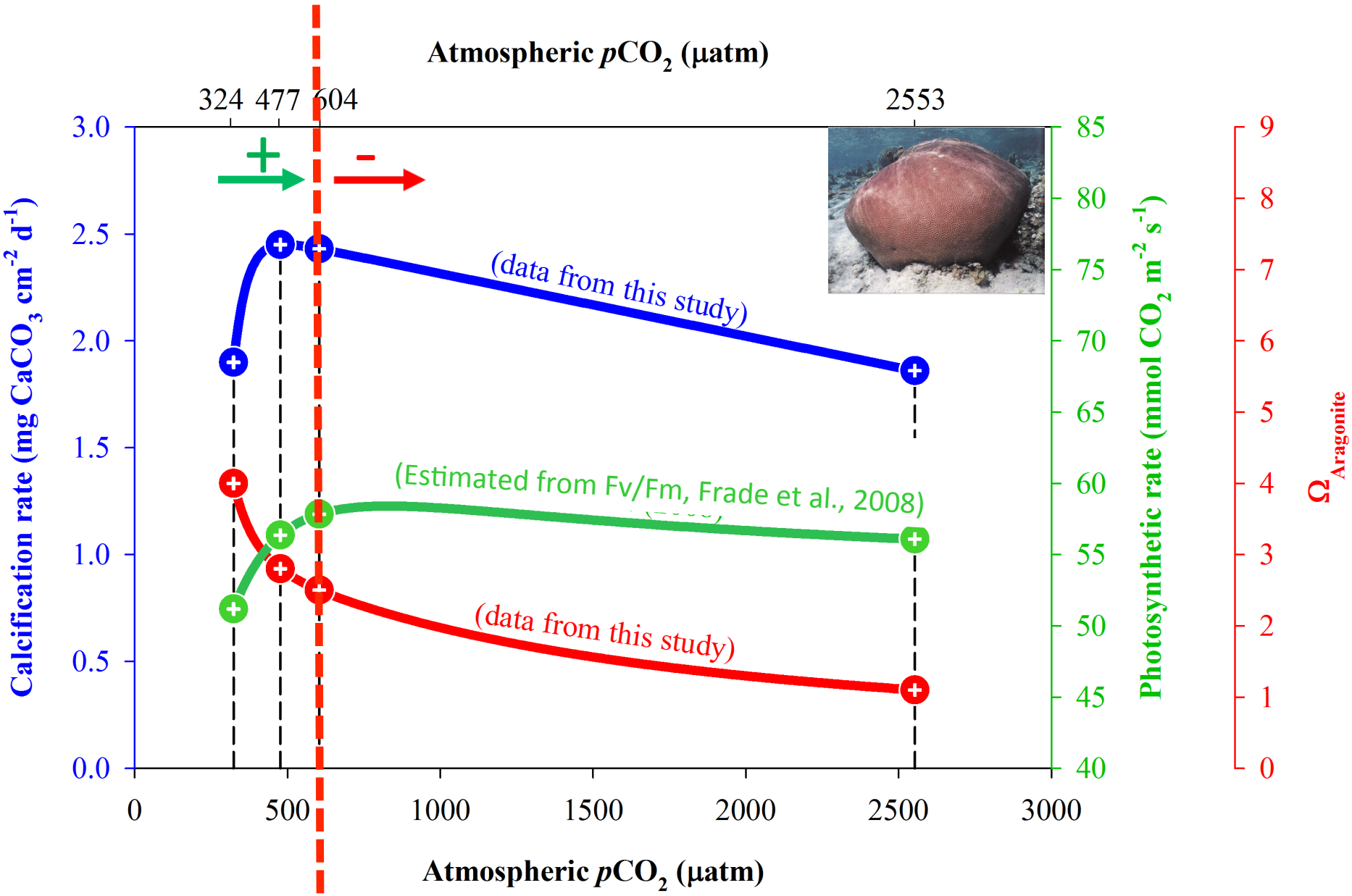
Impacts of OA/warming






Siderastrea siderea

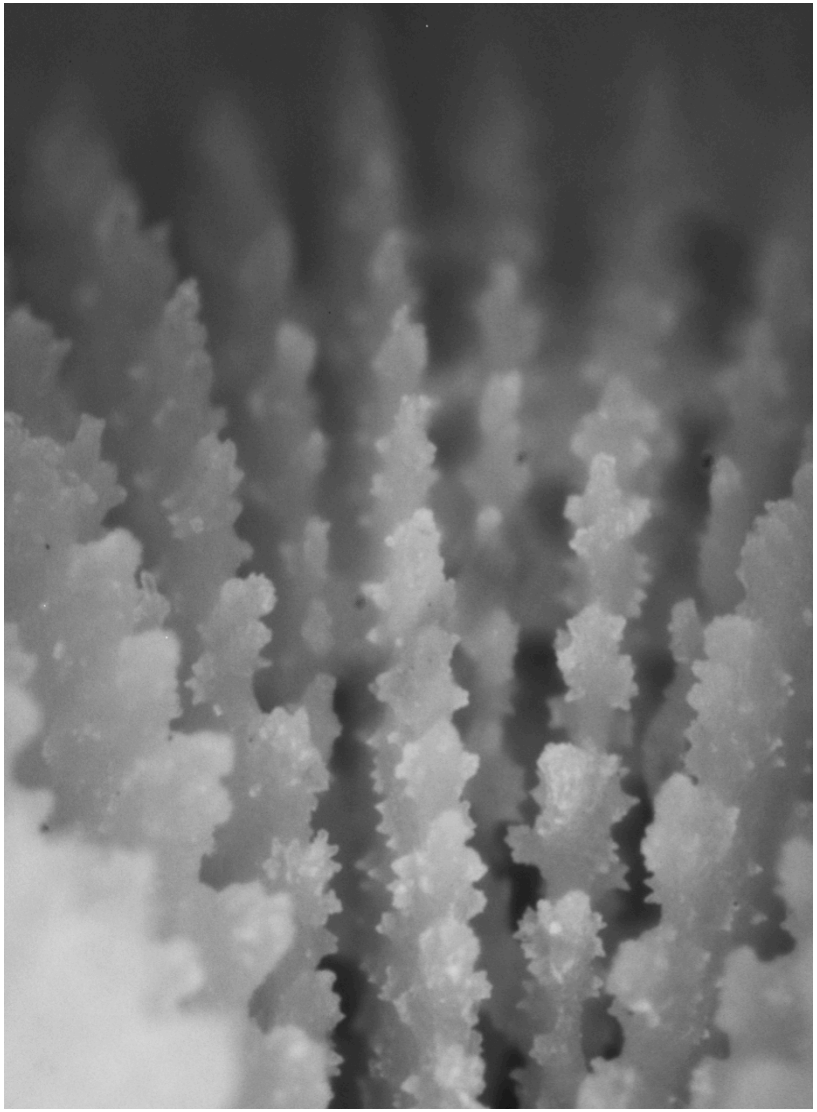
Castillo, Ries, Bruno & Westfield, (2014)



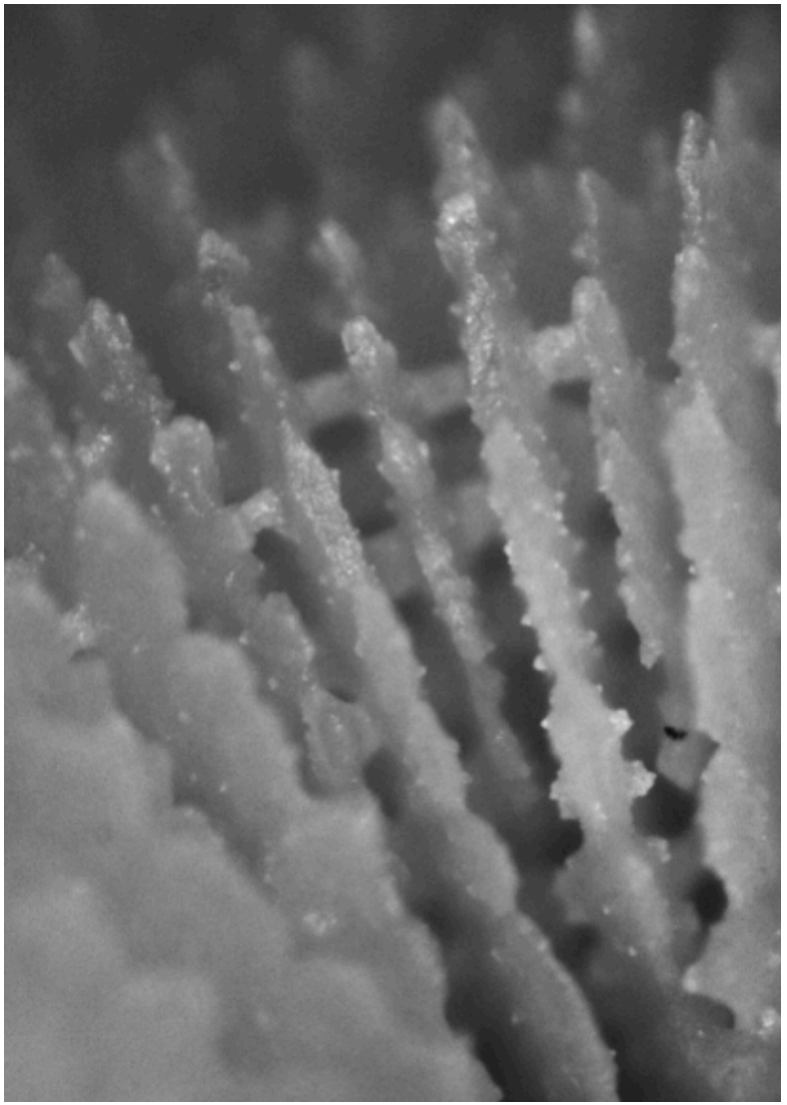
Castillo, Ries, Bruno & Westfield, J. Proc. Roy. Soc. (2014)

Conclusion:
Coral response to both warming and acidification is parabolic if sufficiently broad range of temperature and pCO_2 is investigated

Impact of OA on corallite morphology

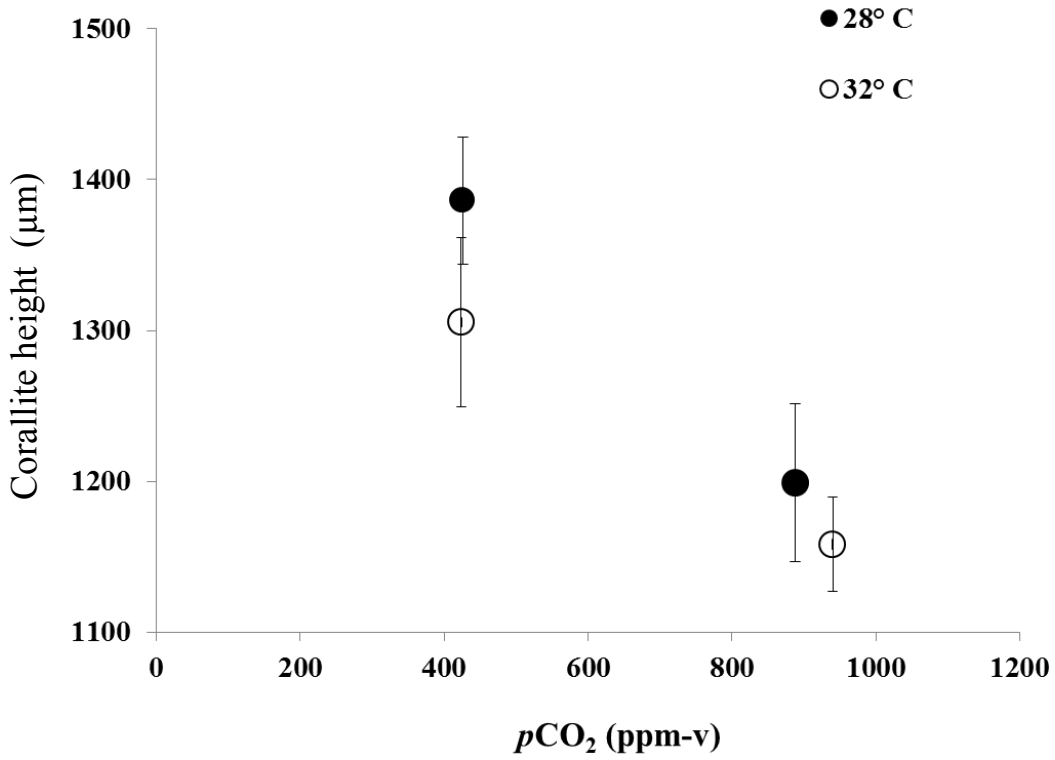


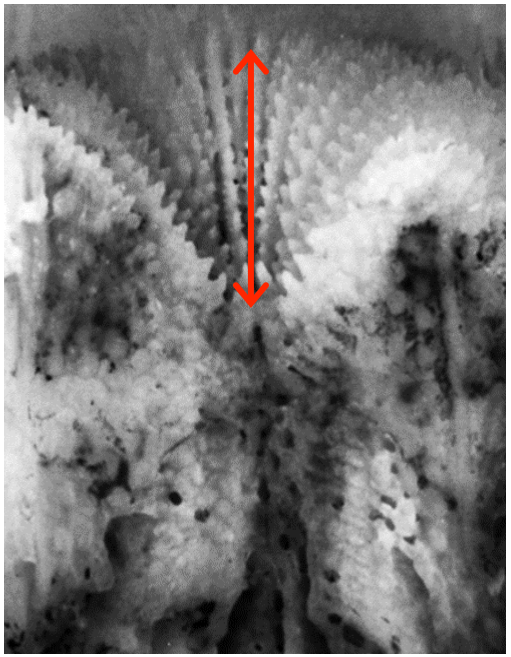
pCO_2 = 400 ppm

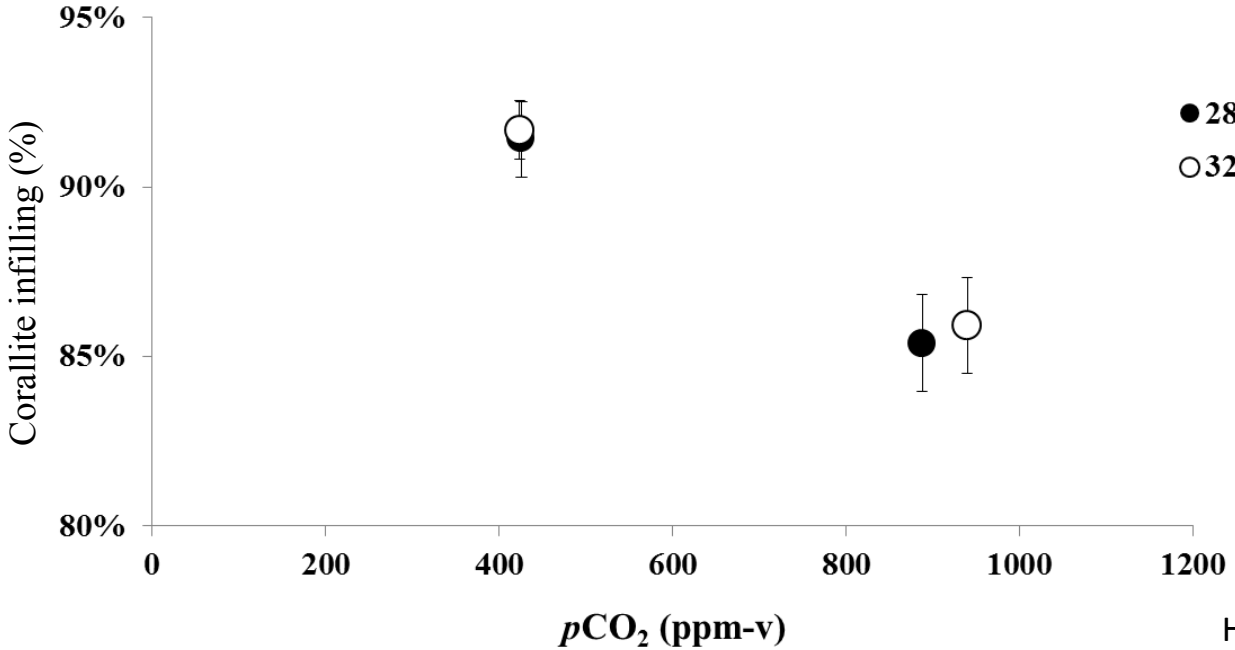


pCO_2 = 900 ppm

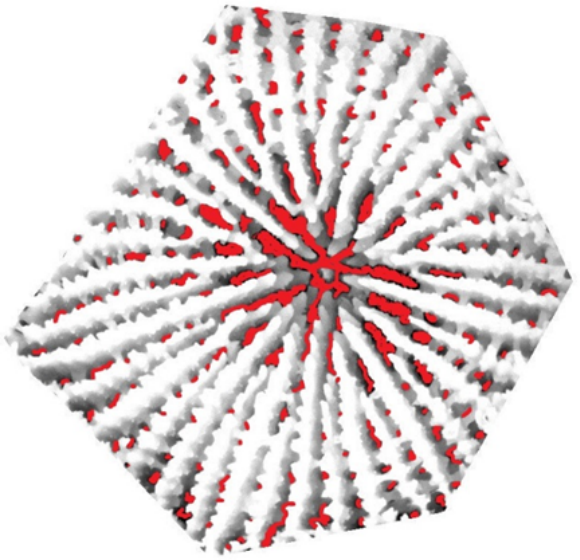
Horvath, Castillo, Westfield & Ries, in prep







28° C
32° C



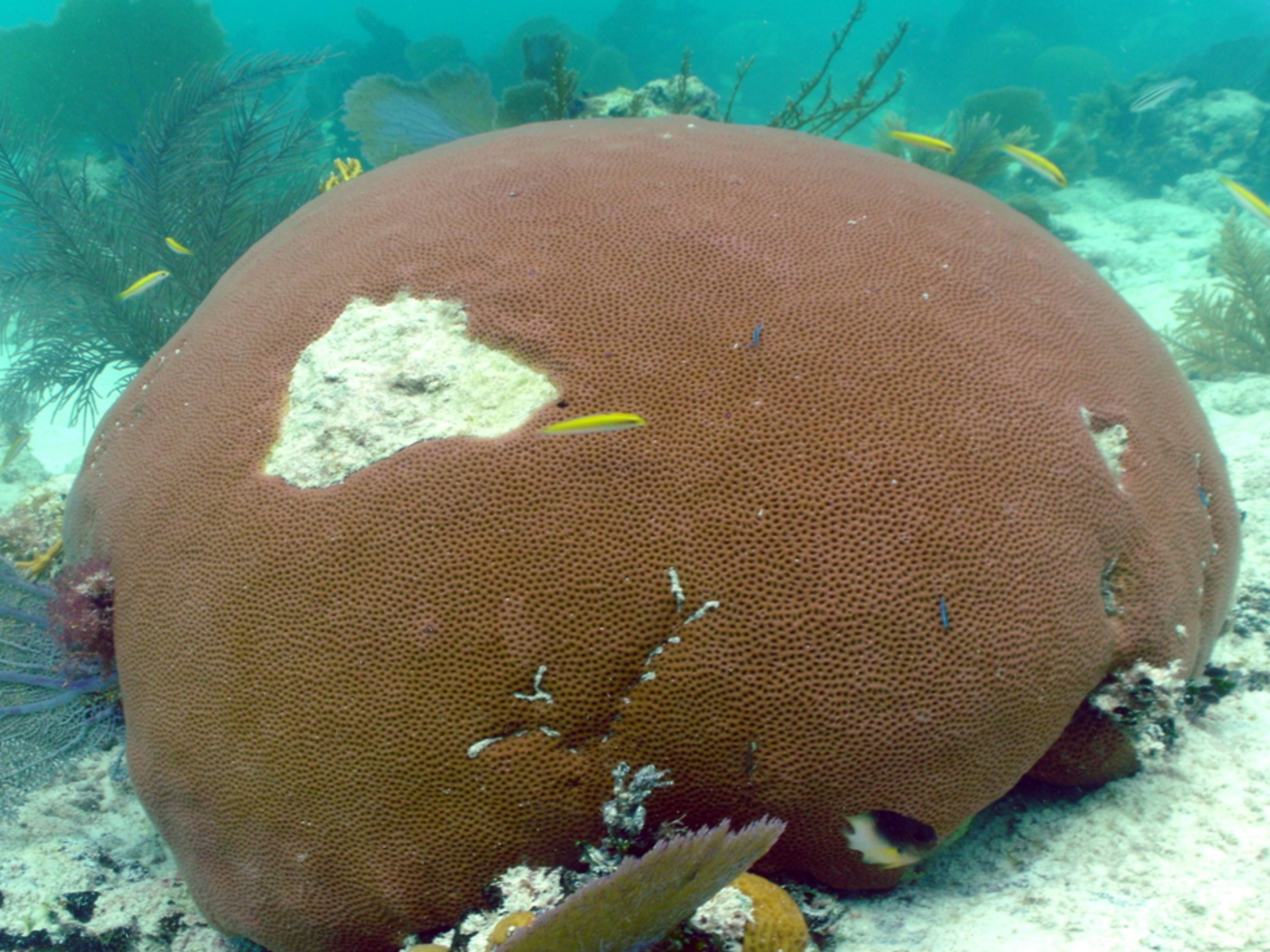
Horvath, Castillo, Westfield & Ries, in prep

Conclusion:
Acidification impacts both calcification rate and corallite morphology, while temperature impacts only calcification rate

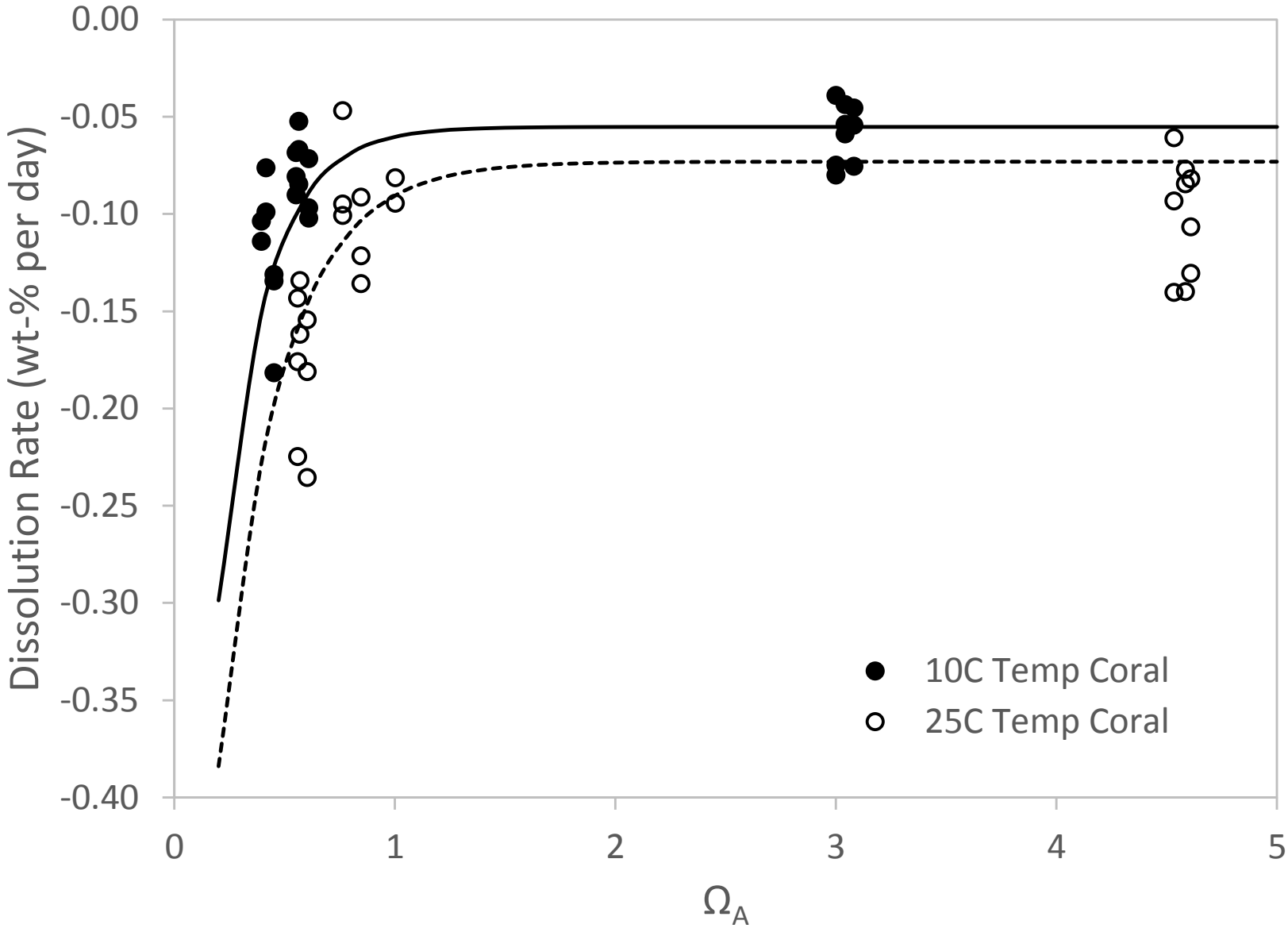
Gross Calcification (beneath tissue)

– Gross Dissolution (of exposed skeleton)

Net Calcification



Dissolution kinetics of coral aragonite



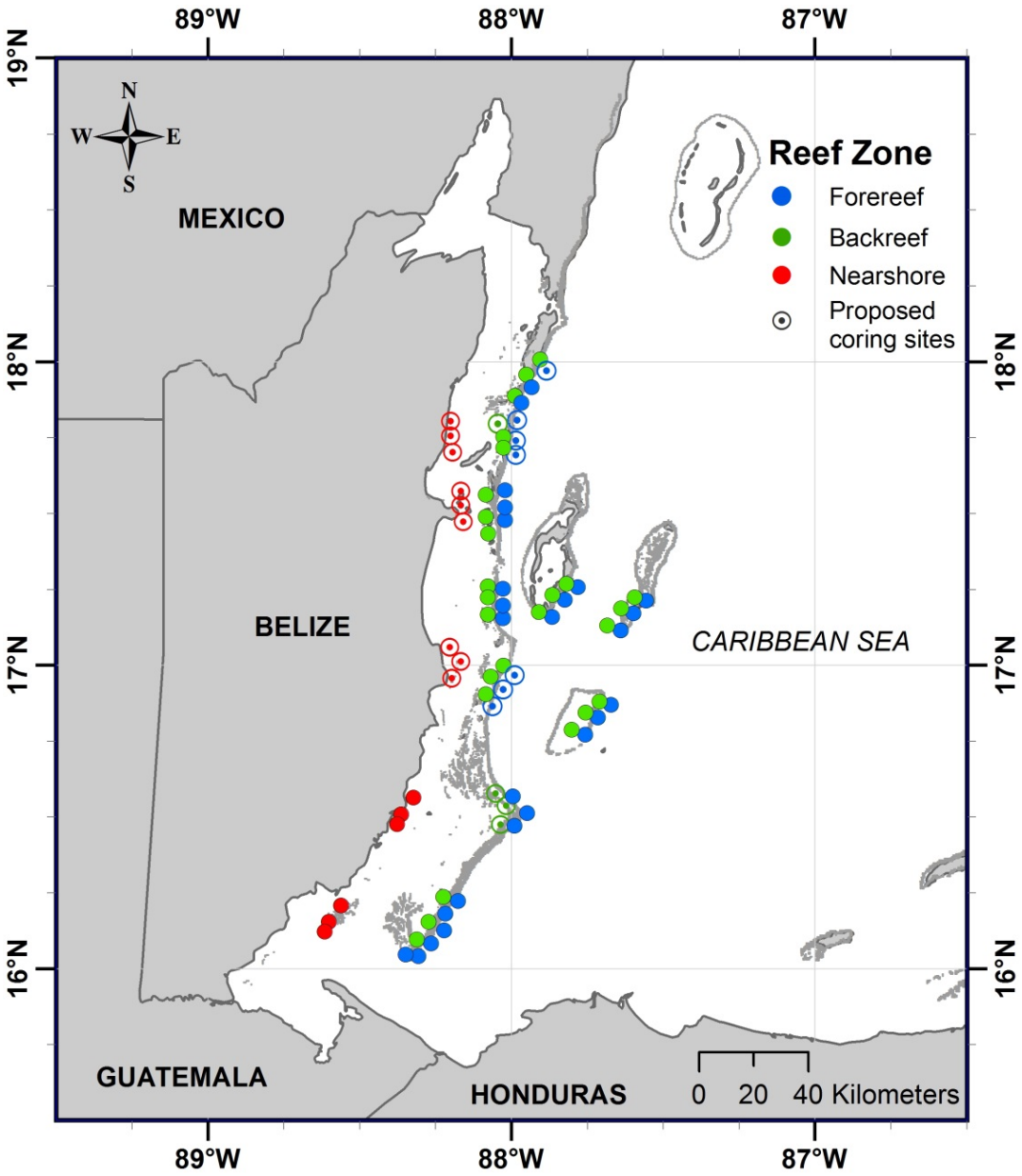
Ries, Ghazaleh, Castillo, Westfield, in preparation

Conclusions:

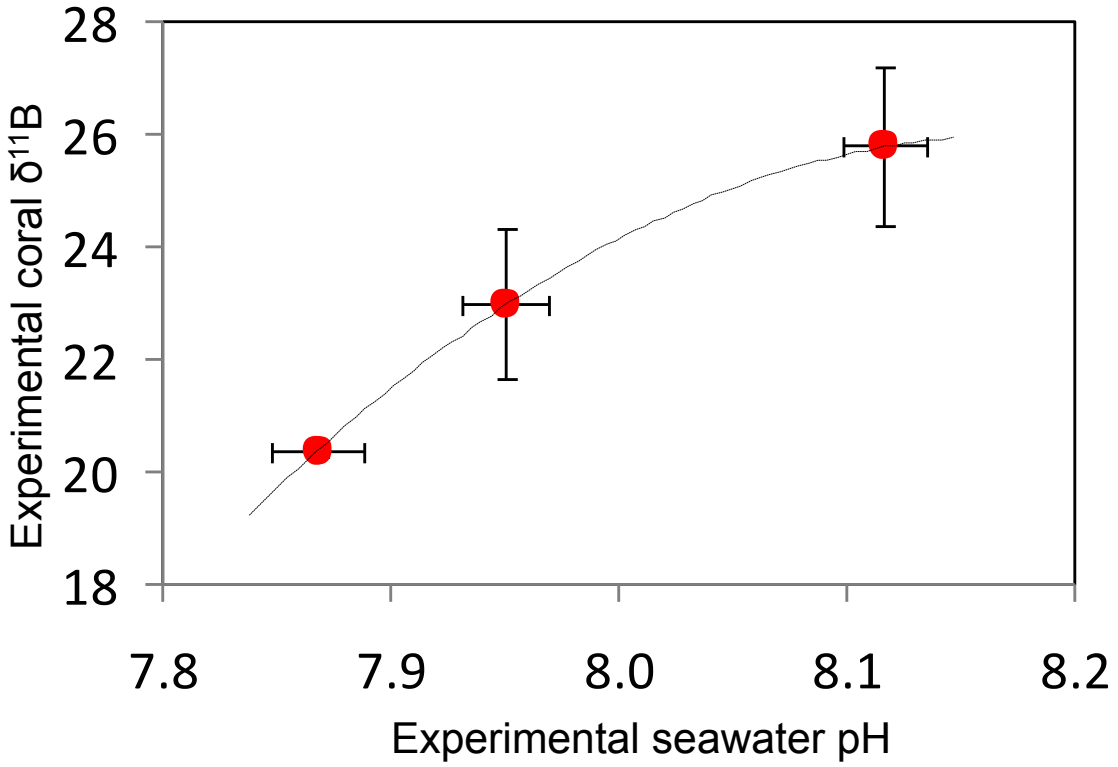
(1) Coral aragonite begins dissolving at $\Omega_A >> 1$, perhaps due to dissolution of ancillary metastable $CaCO_3$ phases such as ACC.

(2) Dissolution is accelerated by warming for a given Ω_A

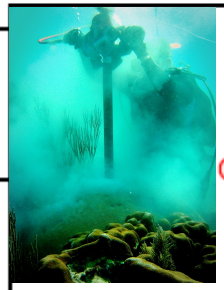
Impact of historical warming and OA on *S. siderea*



Coral $\delta^{11}B$-pH calibration experiment



Fowell, Foster, Ries & Castillo, in prep



Seawater pH
(δ^{11}B-derived)

8.3
8.2
8.1
8.0

Forereef
Backreef

1900 1920 1940 1960 1980 2000

Fowell, Foster, Ries & Castillo, in prep

Normalized linear extension

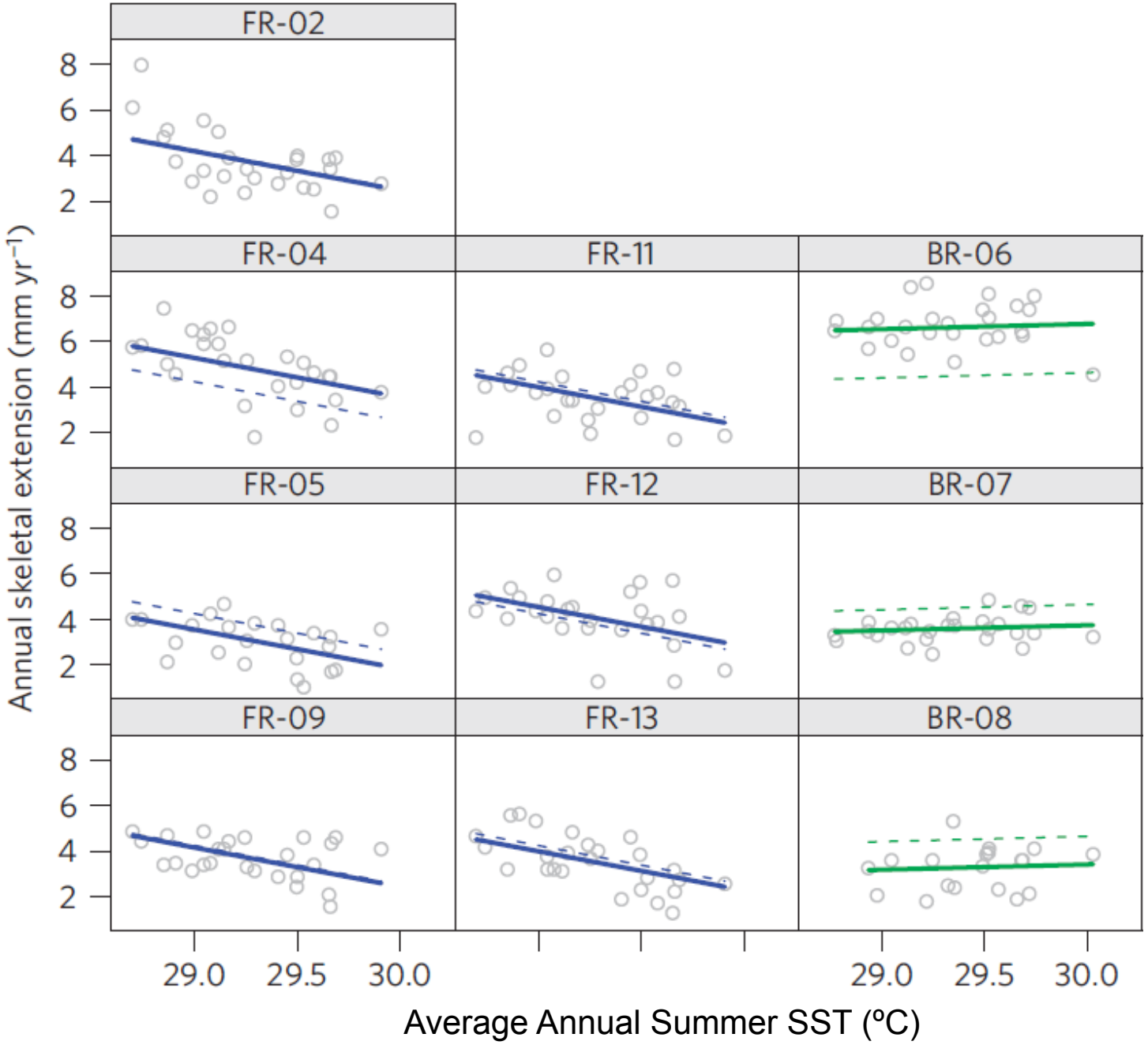
1.5
1.0
0.5

BR

1920 1940 1960 1980 2000

FR

1920 1940 1960 1980 2000

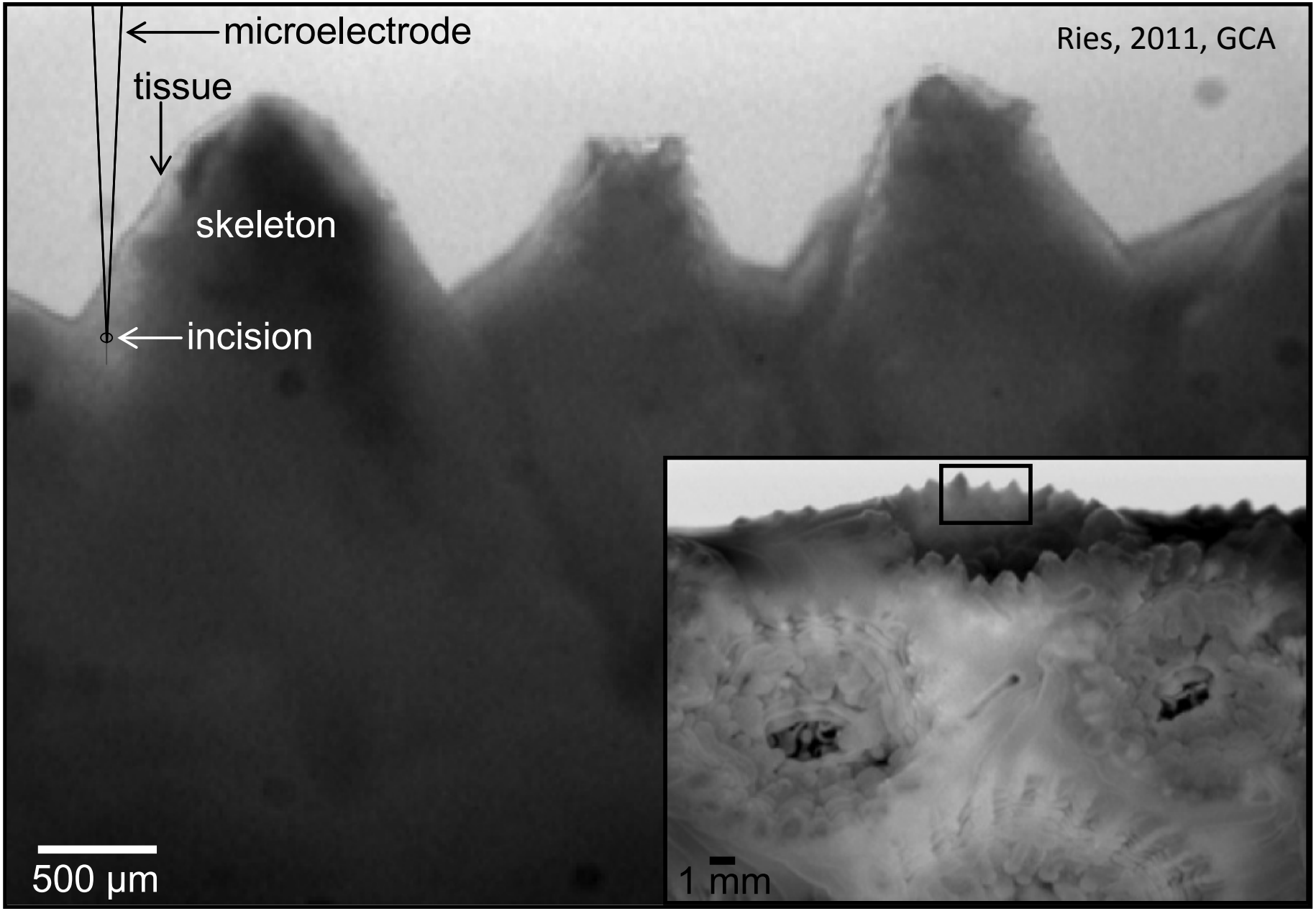


Castillo, Ries, Weiss, Lima 2012, Nature Climate Change

Conclusions:

(1) Backreef waters appear to be acidifying more rapidly than forereef waters on the Meso-American Barrier Reef
(2) However, calcification rate for backreef corals (*S. siderea*) have been more stable over past century than for forereef corals
(3) Coral calcification trends over past century seem have been controlled by warming, not OA

Measurement of coral calcifying fluid pH



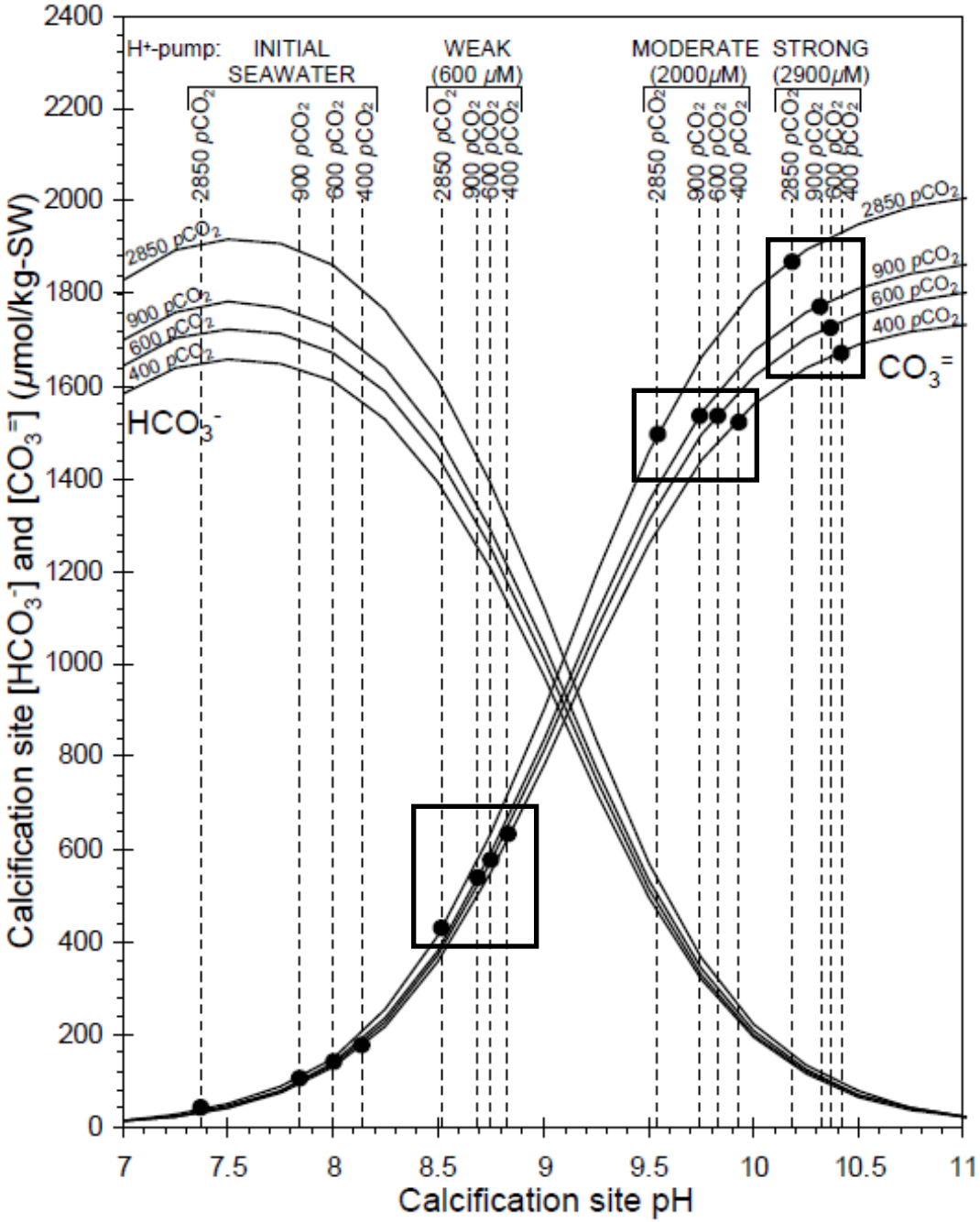
Non-acidified seawater (pCO_2 = 380 ppm; control)

	pH	$[CO_3^{2-}]$	Ω	$[H^+]_F/[H^+]_I$
SEAWATER	8.16±0.02	182±5	2.9±0.1	87.7 ±17.8
CALCIFYING FLUID	10.10±0.11	1587±30	25.6±0.5	

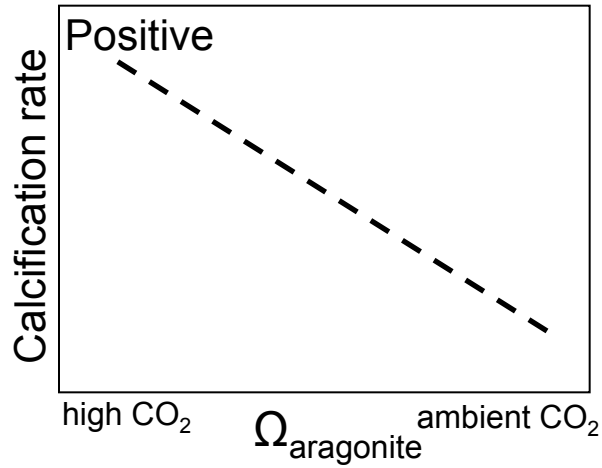
Acidified seawater (pCO_2 = 1940 ppm)

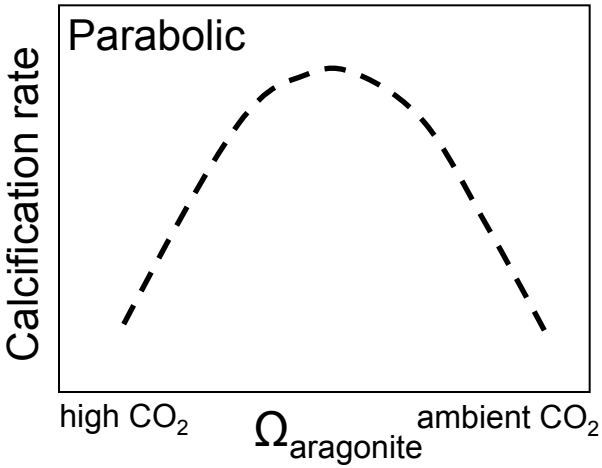
	pH	$[CO_3^{2-}]$	Ω	$[H^+]_F/[H^+]_I$
SEAWATER	7.47±0.01	39±1	0.6±0.0	85.5 ±9.9
CALCIFYING FLUID	9.40±0.06	1158±52	18.7±0.8	

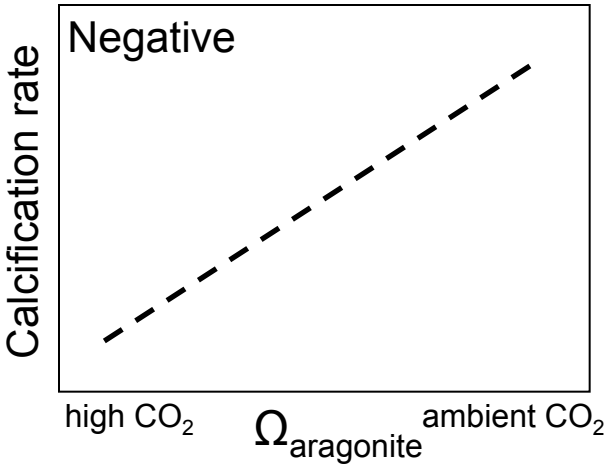
Ries, 2011, GCA

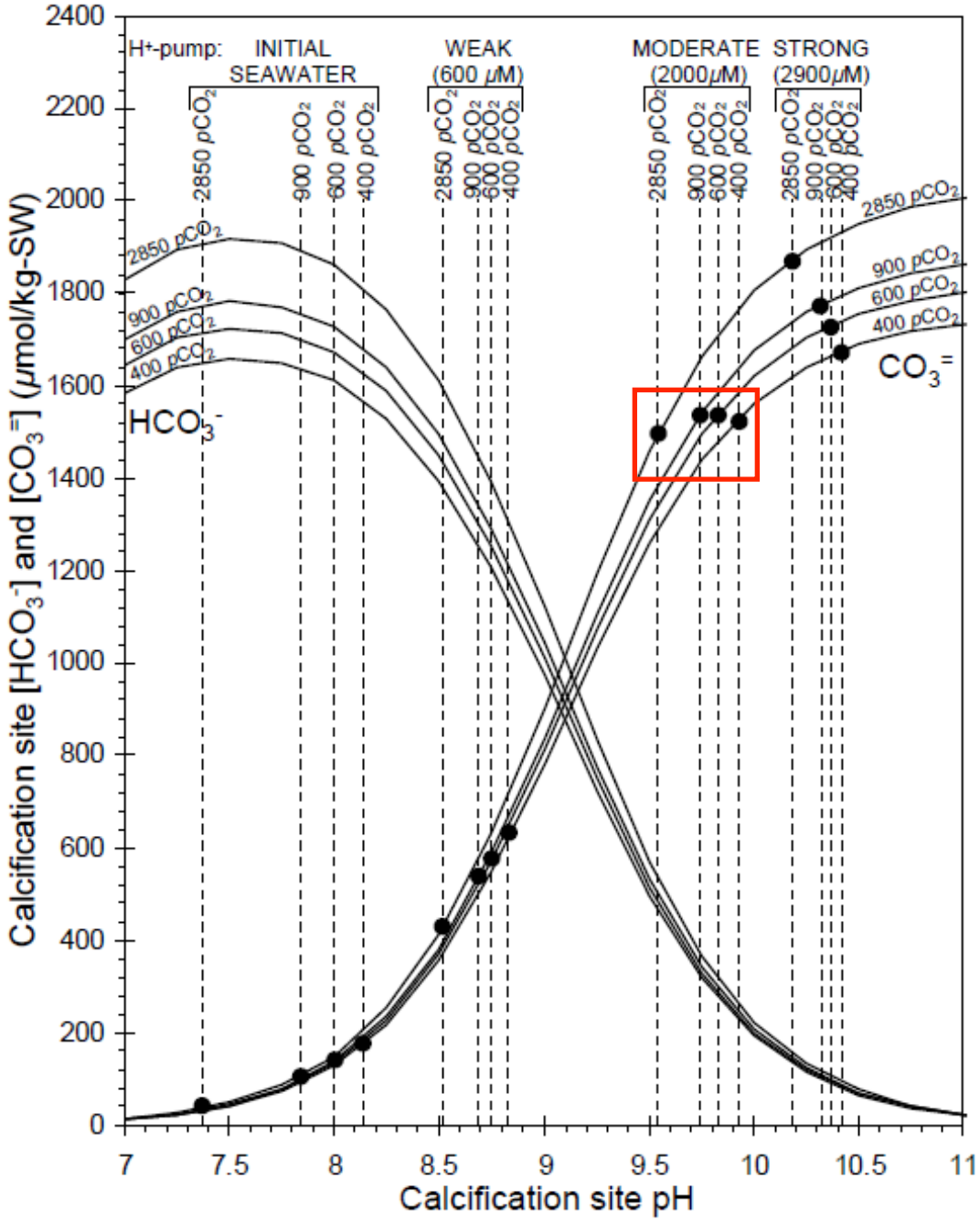


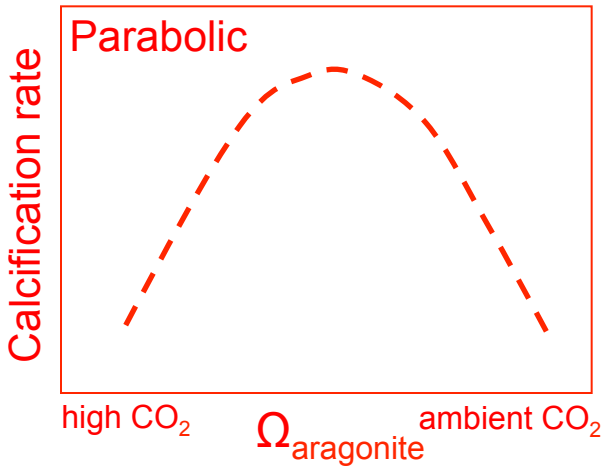
Ries, 2011, GCA



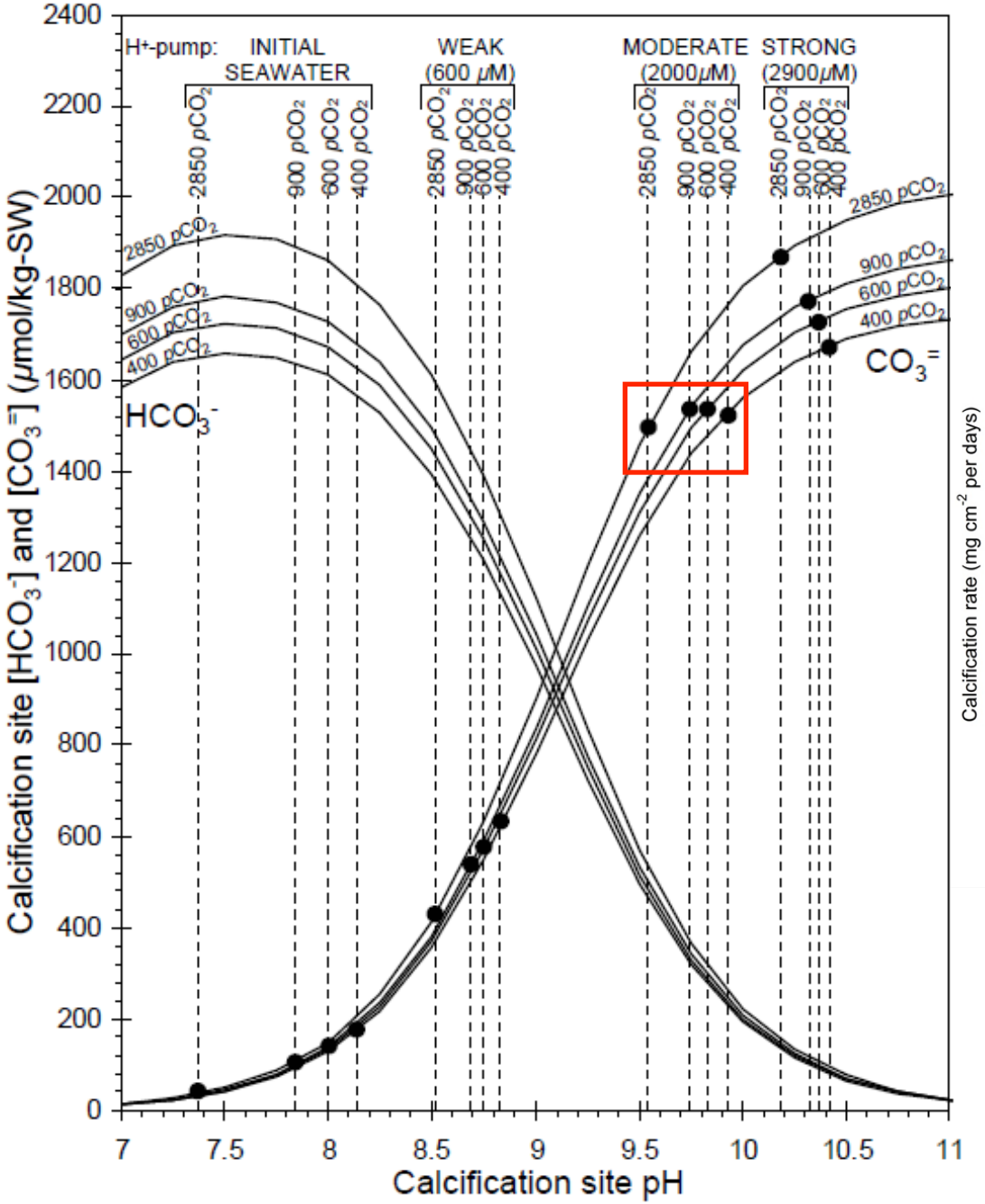


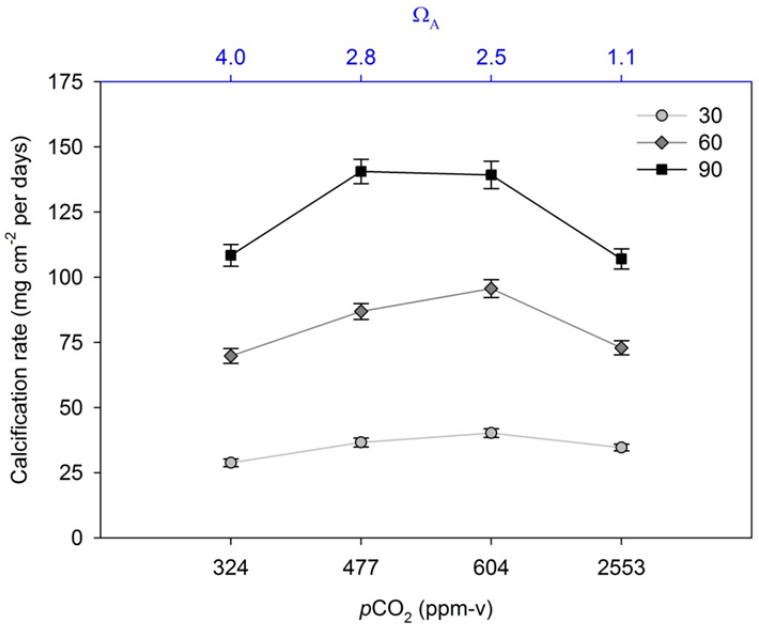






Ries, 2011, GCA





Ries, 2011, GCA

Conclusions:

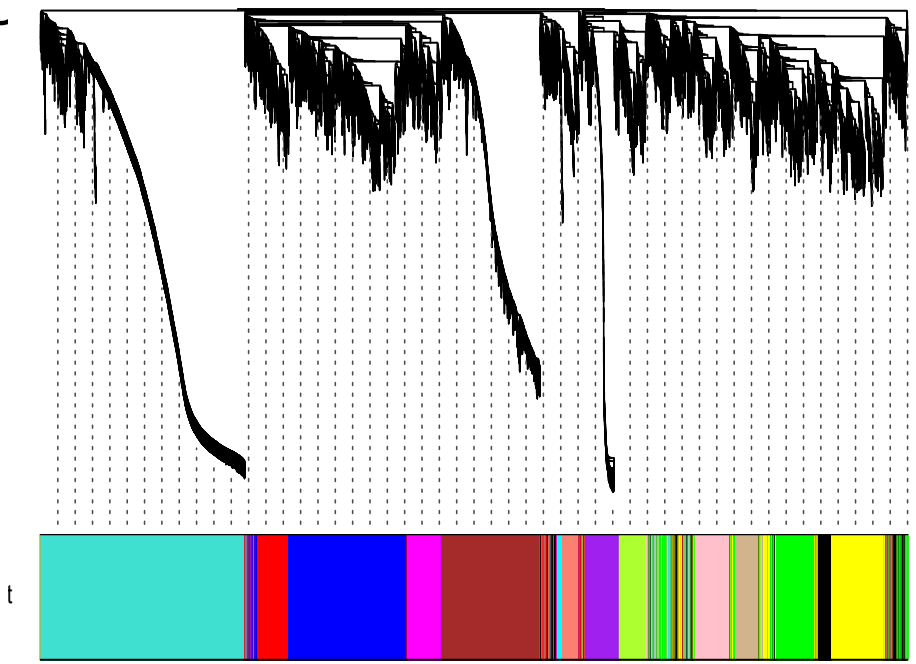
(1) Corals target fixed $[H^+]_E/[H^+]_I$ regardless of ambient pH
(2) Corals continue calcifying under extremely elevated pCO_2 by substantially raising pH of calcifying fluid (ca. 2 pH units)
(3) Modelled $[CO_3^{2-}]$ at site of calcification is consistent with observed coral calcification trends under variable pCO_2

Coral transcriptomic response to OA and warming

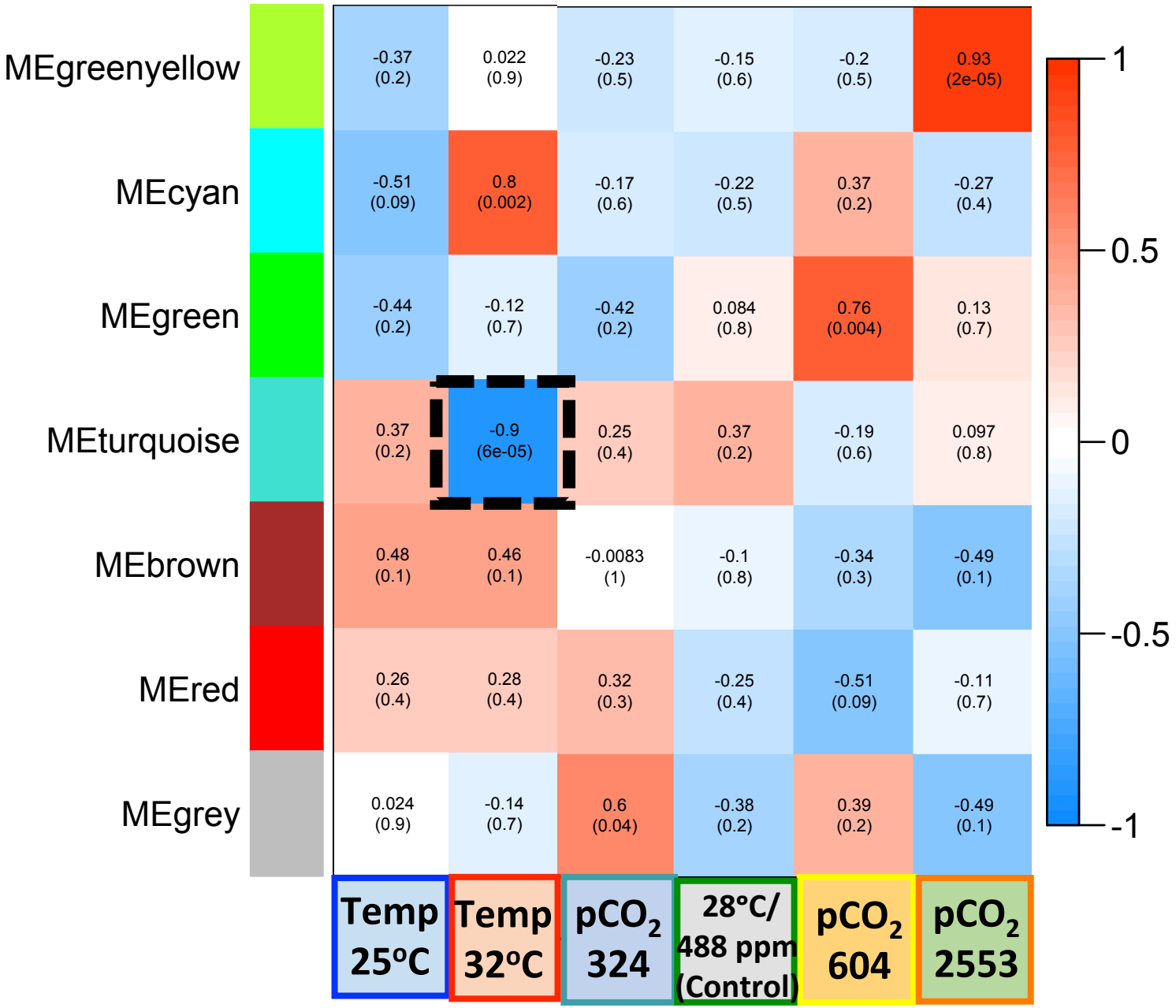
- Gene expression determined by Next Gen RNAseq

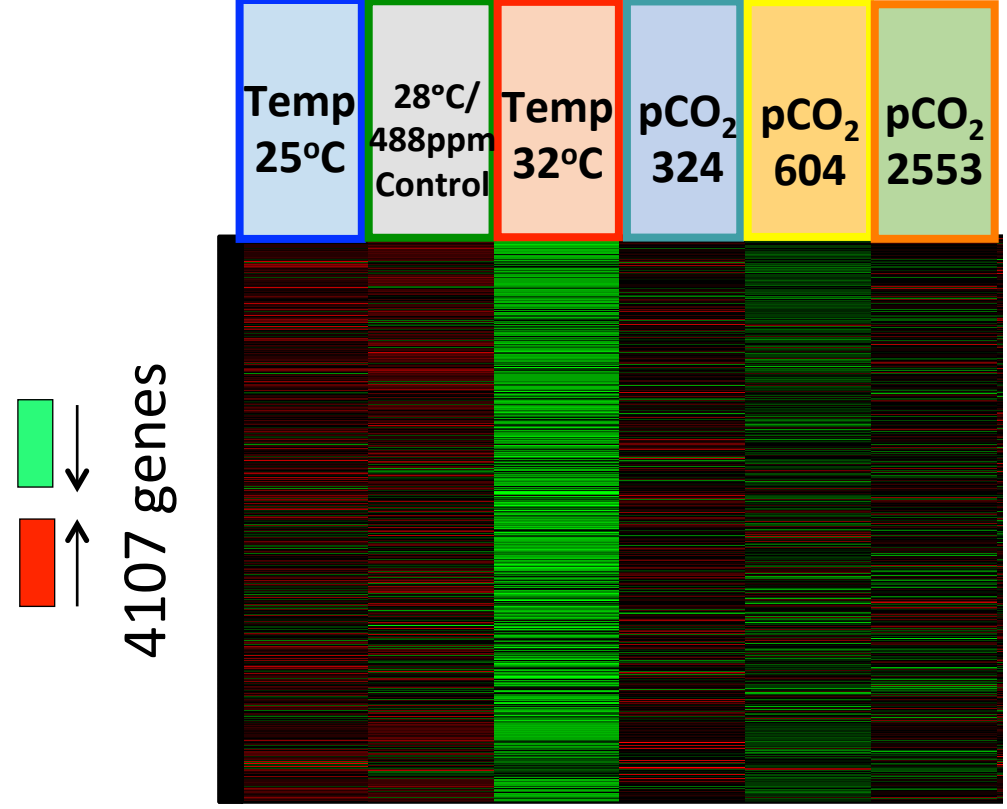
- Patterns in differential gene expression amongst treatments determined by Weighted Gene Co-expression Network Analysis (WGCNA)

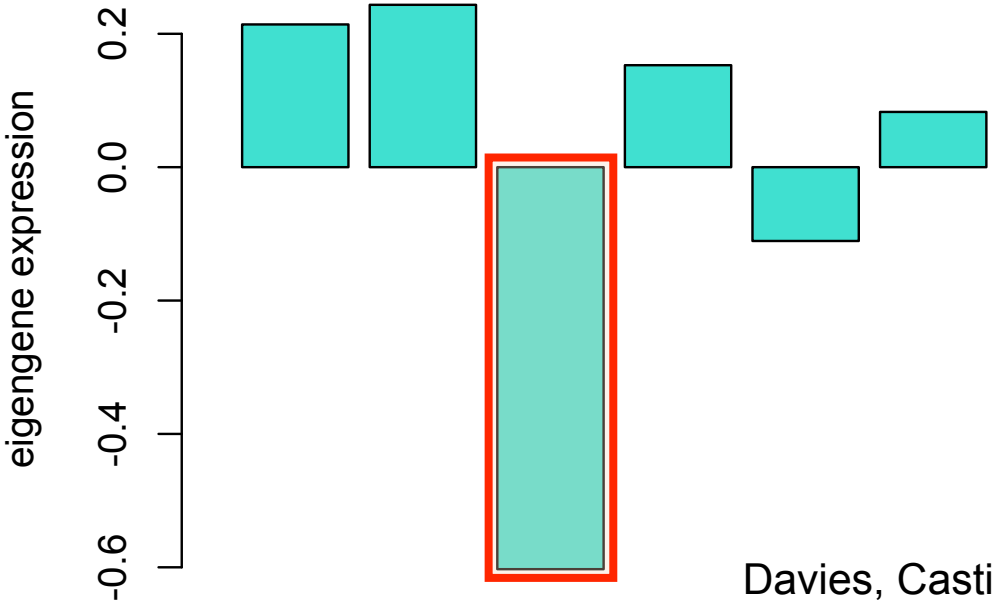
- Colored mc d groups of genes



Davies, Castillo, Marchetti, Ries, in prep

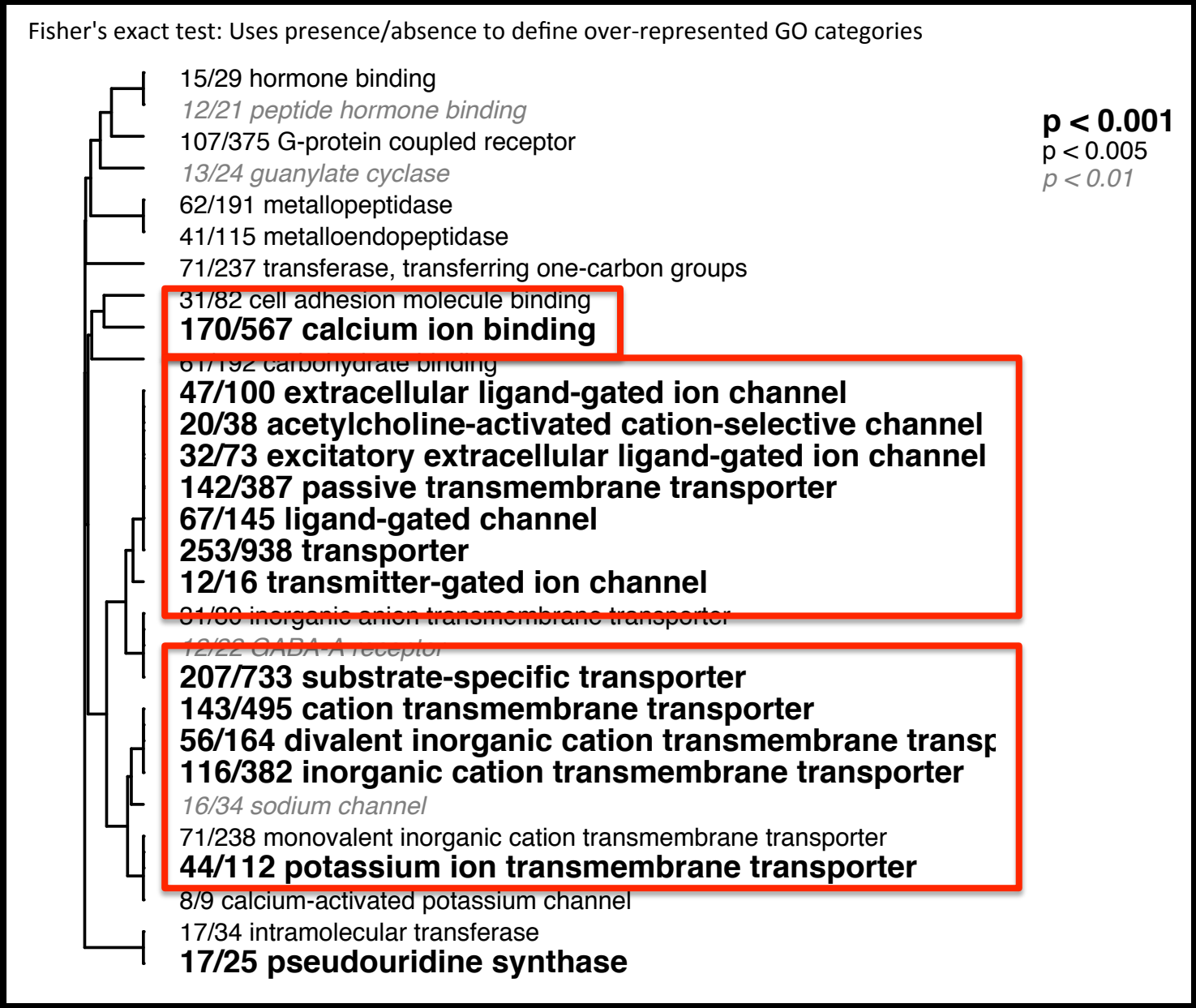




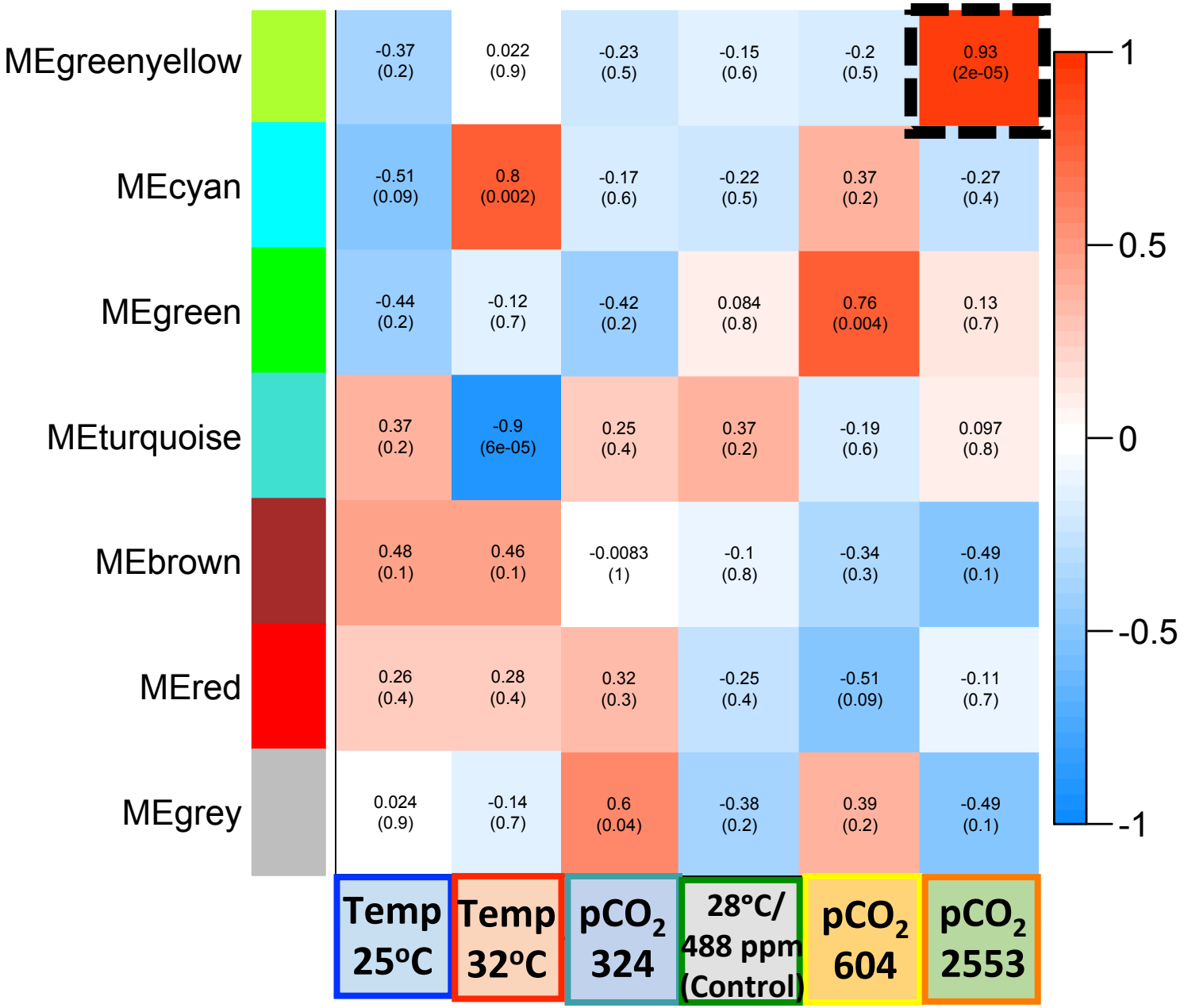


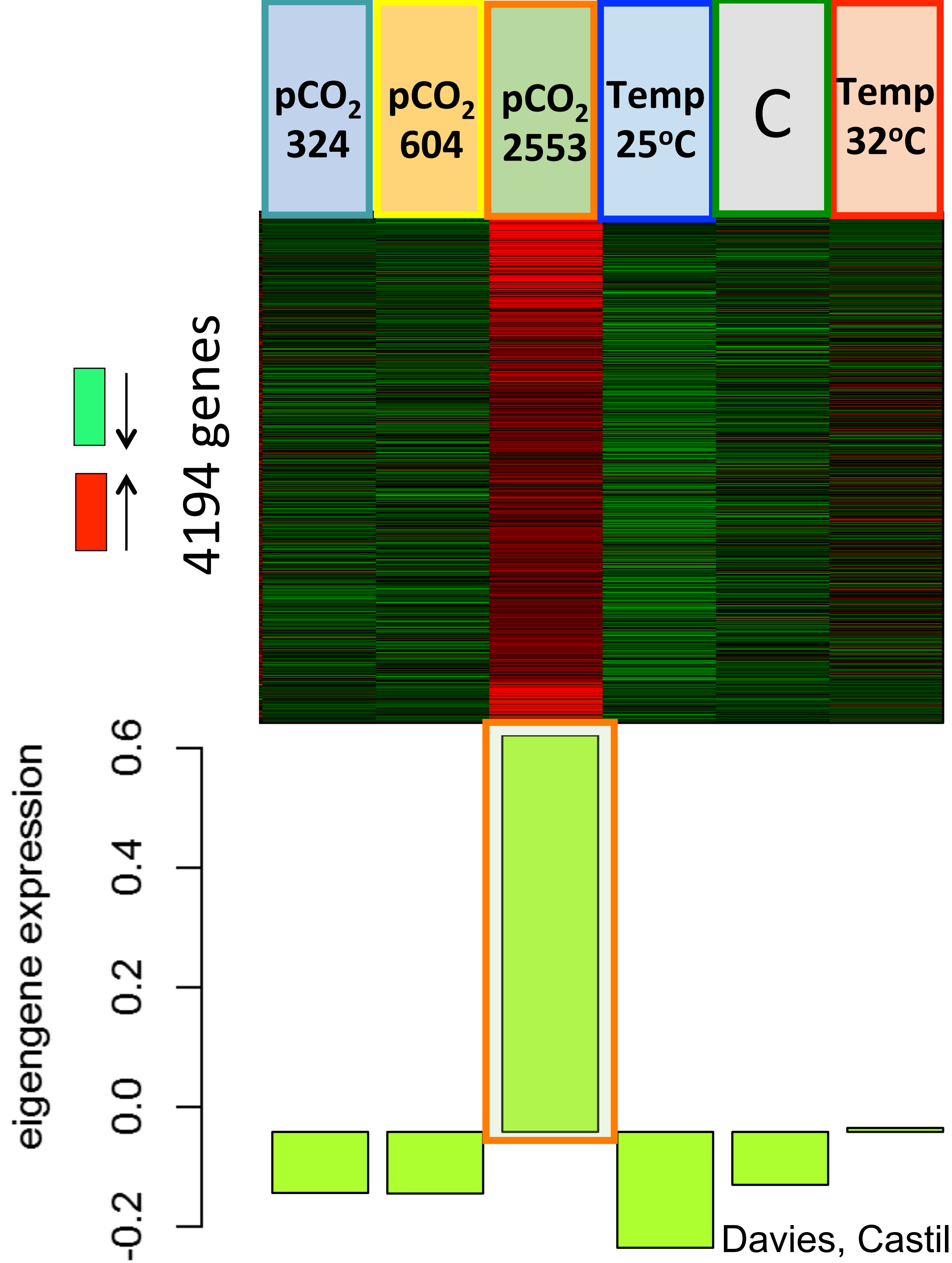
Davies, Castillo, Marchetti, Ries, in prep

Module gene ontology enrichment at highest temperature



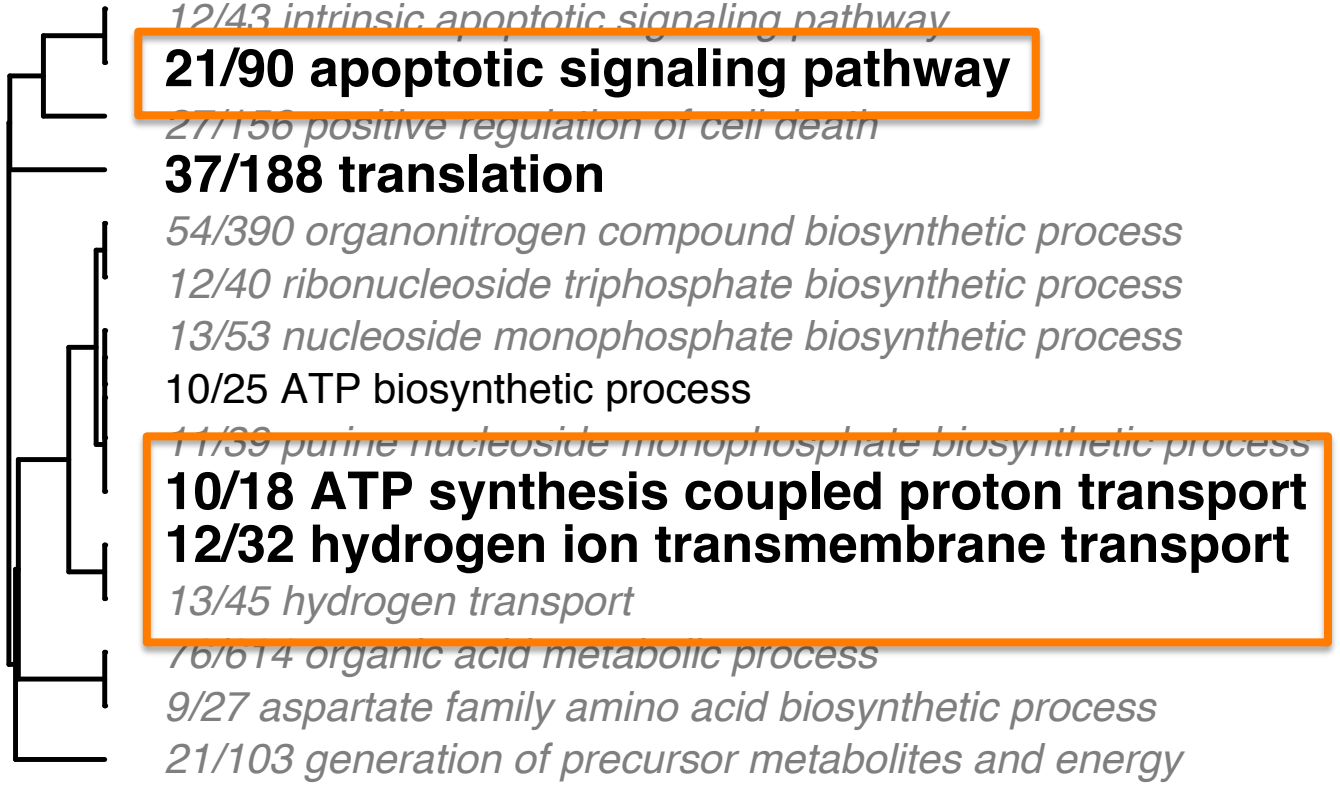
Davies, Castillo, Marchetti, Ries, in prep

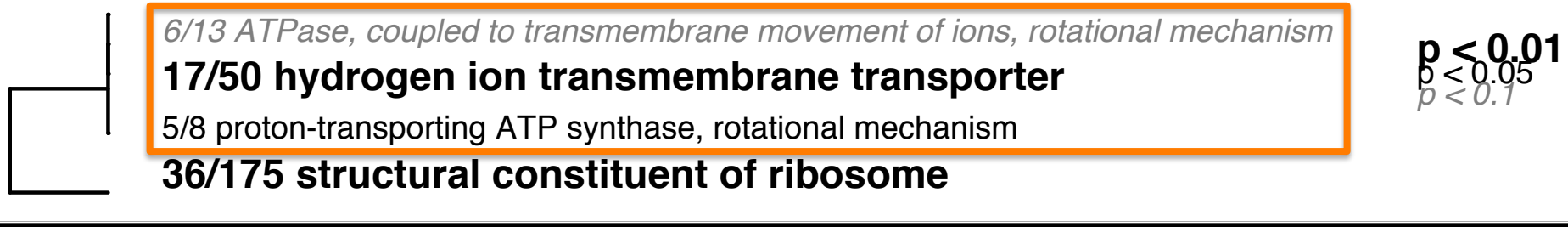




Davies, Castillo, Marchetti, Ries, in prep

Module gene ontology enrichment at highest pCO_2





Conclusions:

(1) Ion-transport genes are preferentially **down-regulated** under elevated temperature, but **up-regulated** under elevated pCO_2 – a possible reason why corals seem to respond more negatively to warming than to CO_2-induced acidification

(2) Suggests that corals are indeed working harder to maintain calcification rates under elevated pCO_2, which must come at some energetic cost

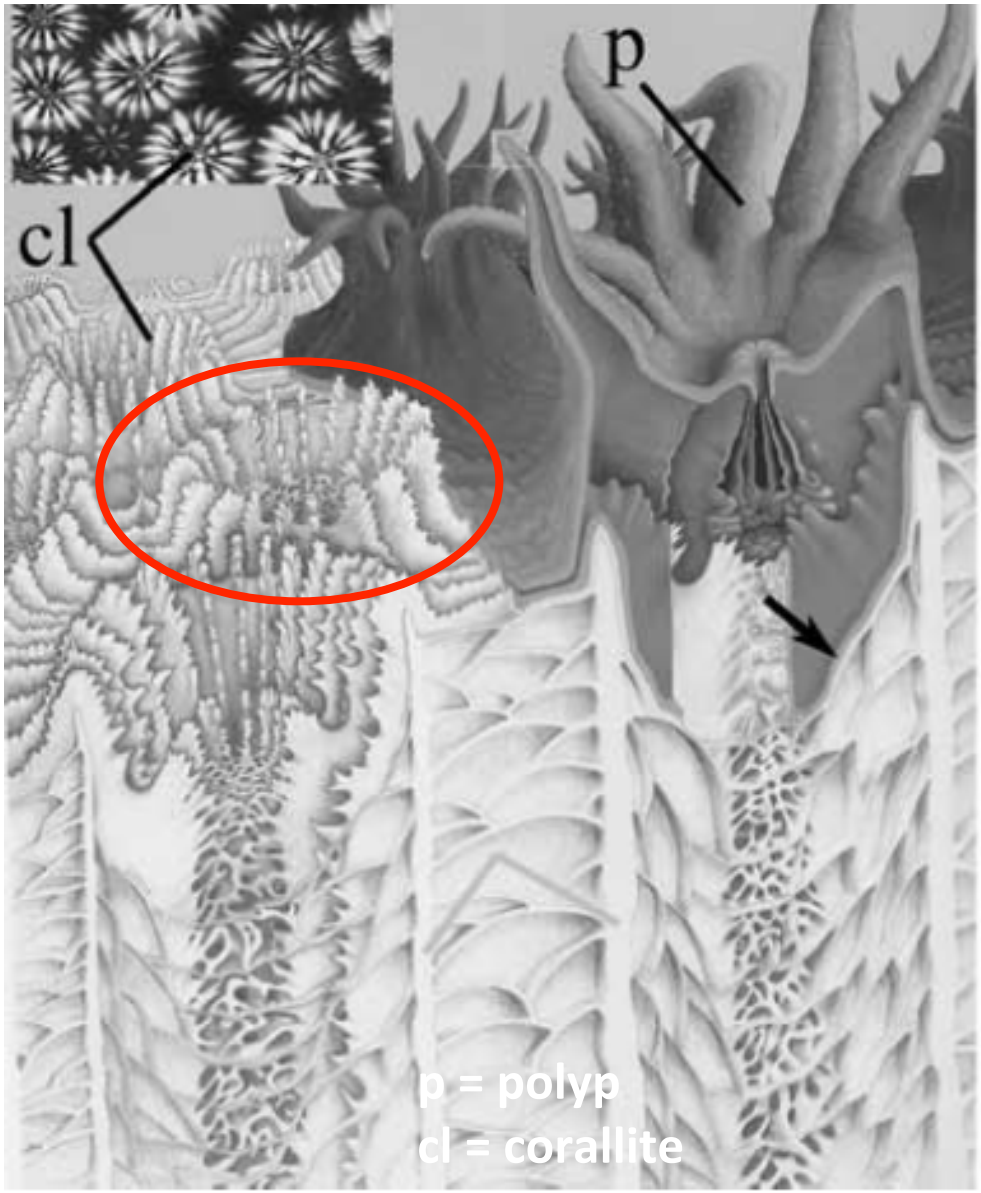
Financial Support♪

NSF-OCE/MGG 1459706, 1437371, 1429373, 1357665♪
NOAA NA14NMF4540072, NA13OAR4310186♪
♪
♪


Isaac Westfield
Travis Courtney
Jane Lee
Sarah Davies
Thank you
Karl Castillo
Areeg Rehman
Elaine Chow
Kimm Horvath
Laura Brown

End

Approach: Morphology

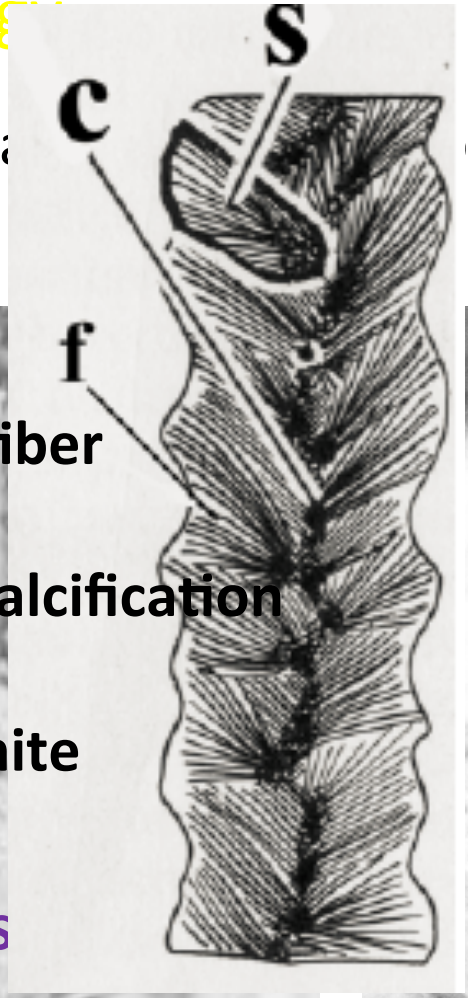


Modified from Veron (1993)

Approach: Morphology

Septal Morphology

- Measured via y



- **F – aragonite fiber**
- **C – center of calcification**
- **S - sclerodermite**

Septal width

Modified from Veron (1993)

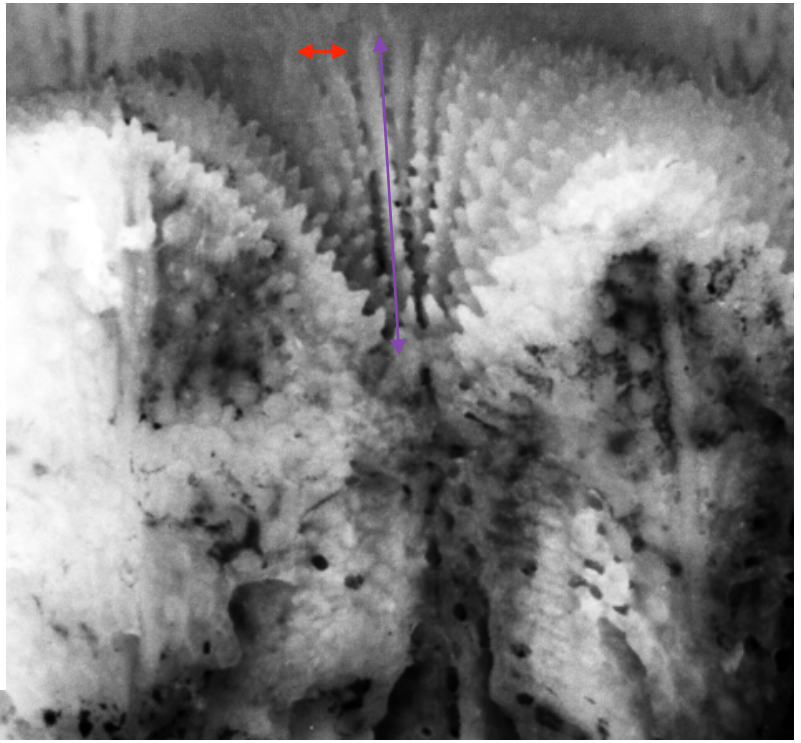
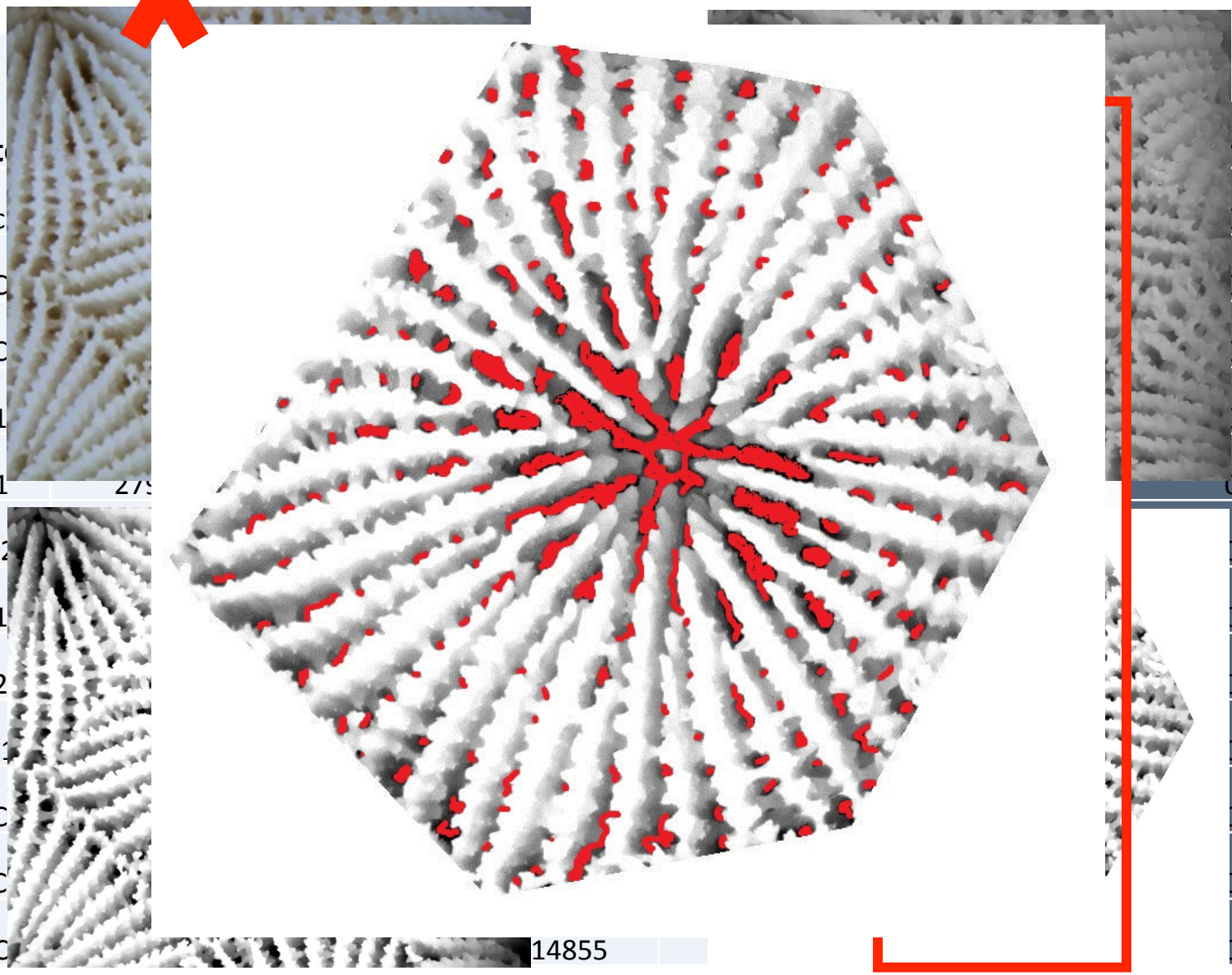


Image from study

Modified from Cohen & McConnaughey (2003)

Methods: Photomicrographic Analysis

Septal width measurement

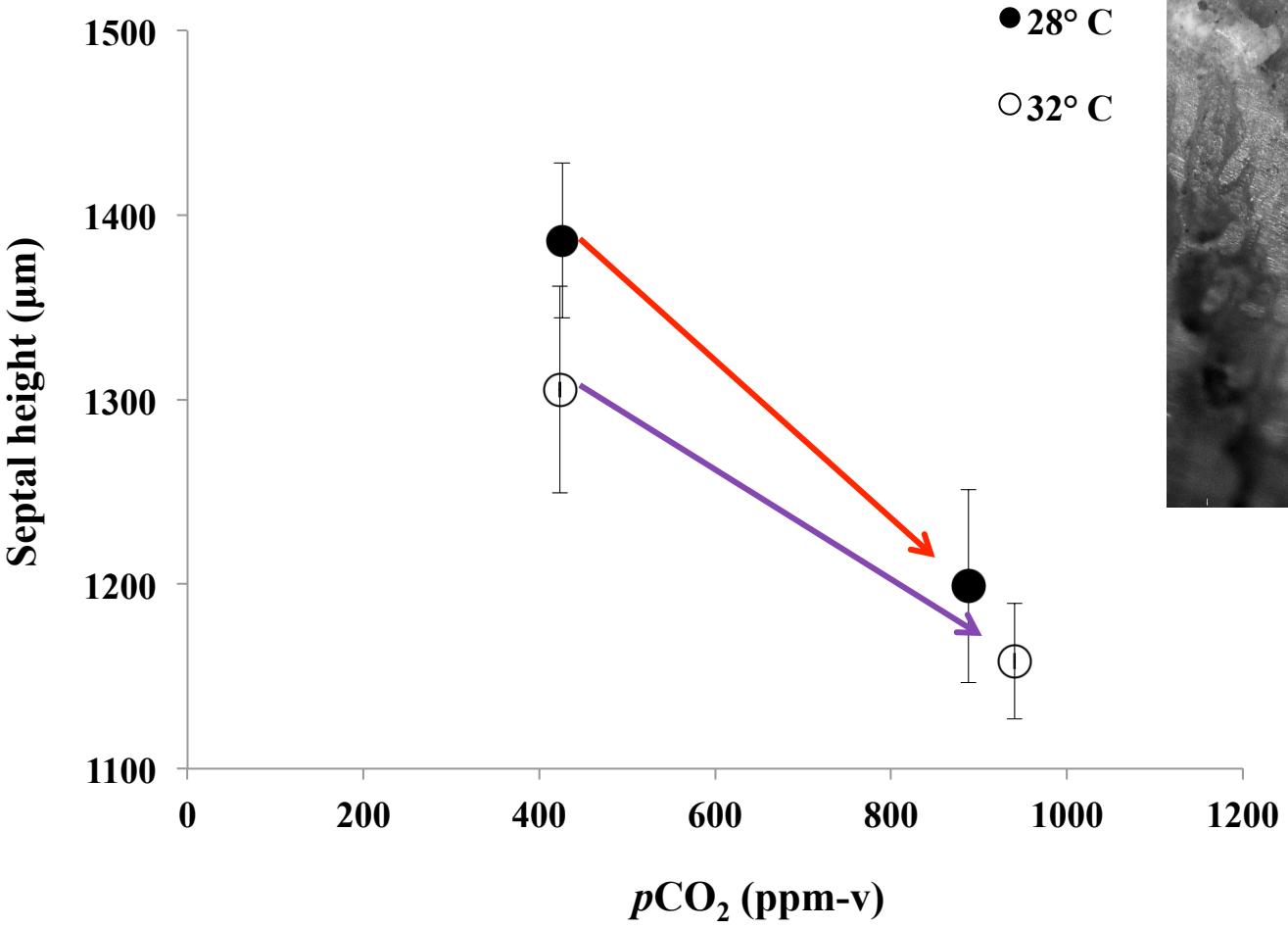


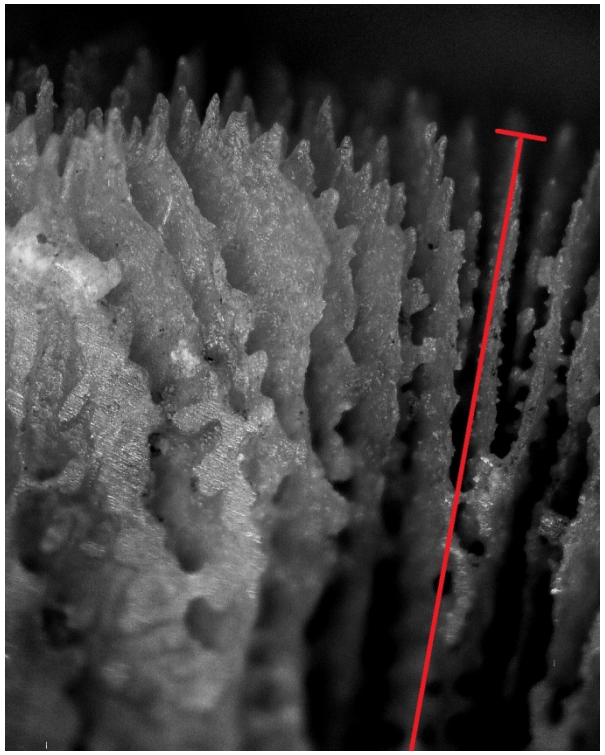
Corallit	to.White
P102a_c	0.09
A104a_C	0.04
A105a_C	0.12
AS9_C1	0.07
G12_C1	0.08
GS4a_C2	0.18
KBb_C1	0.07
KCb_C2	0.06
OS7a_C1	0.03
P102b_C	0.13
P105a_C	0.10
O105a_C	0.18

14855

Results: Septal Morphology

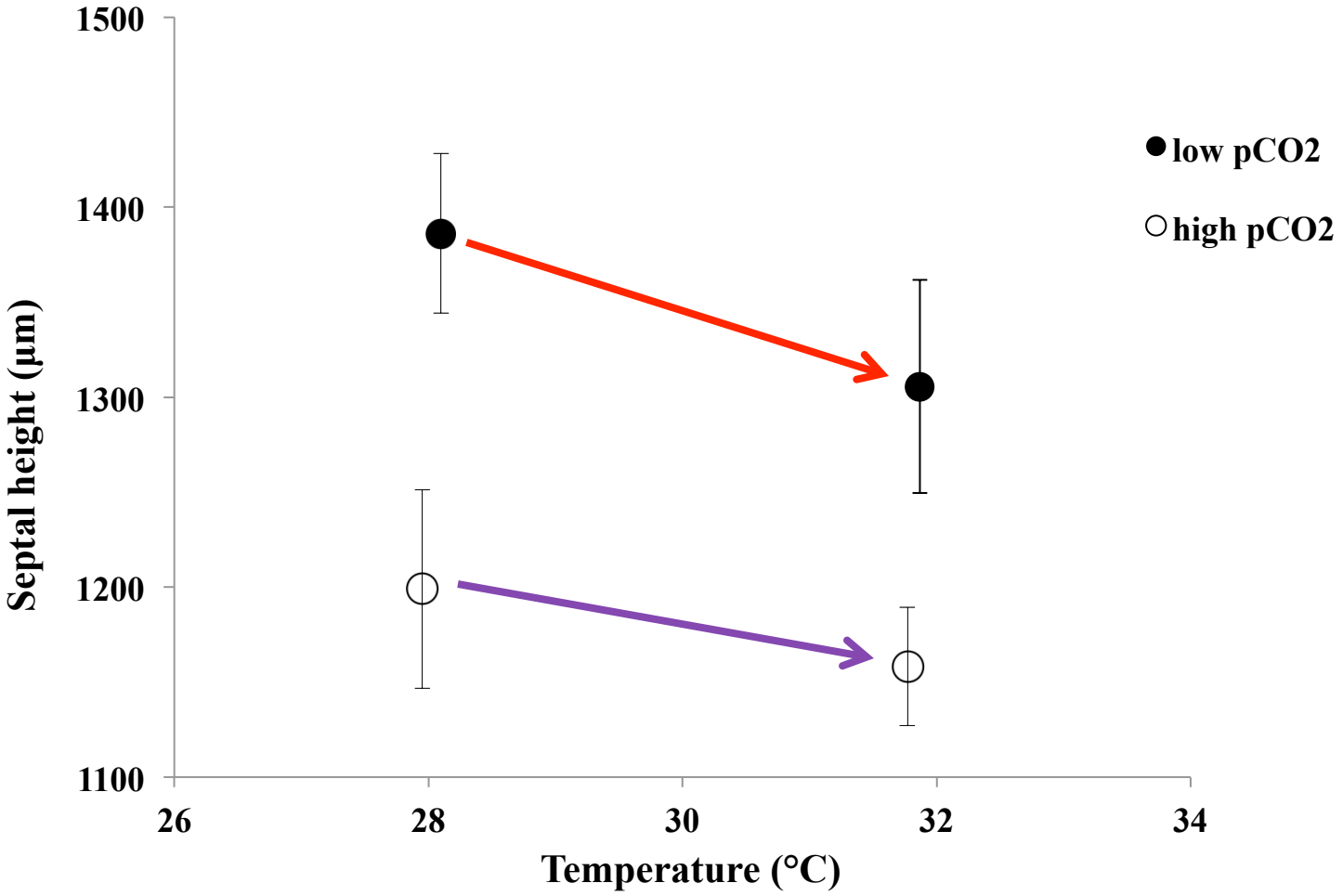
Septal Height: pCO_2 Effect





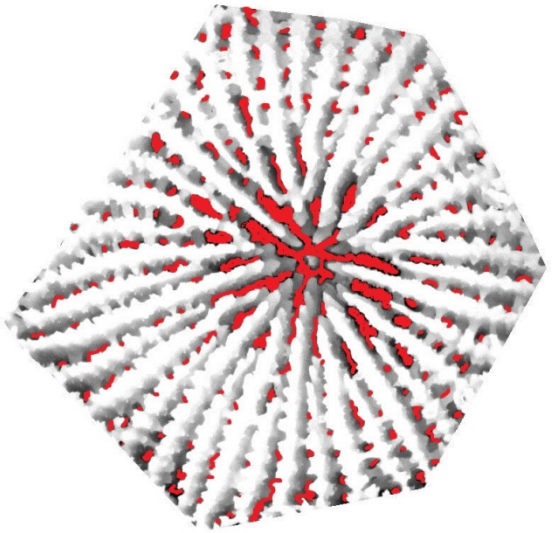
Results: Septal Morphology

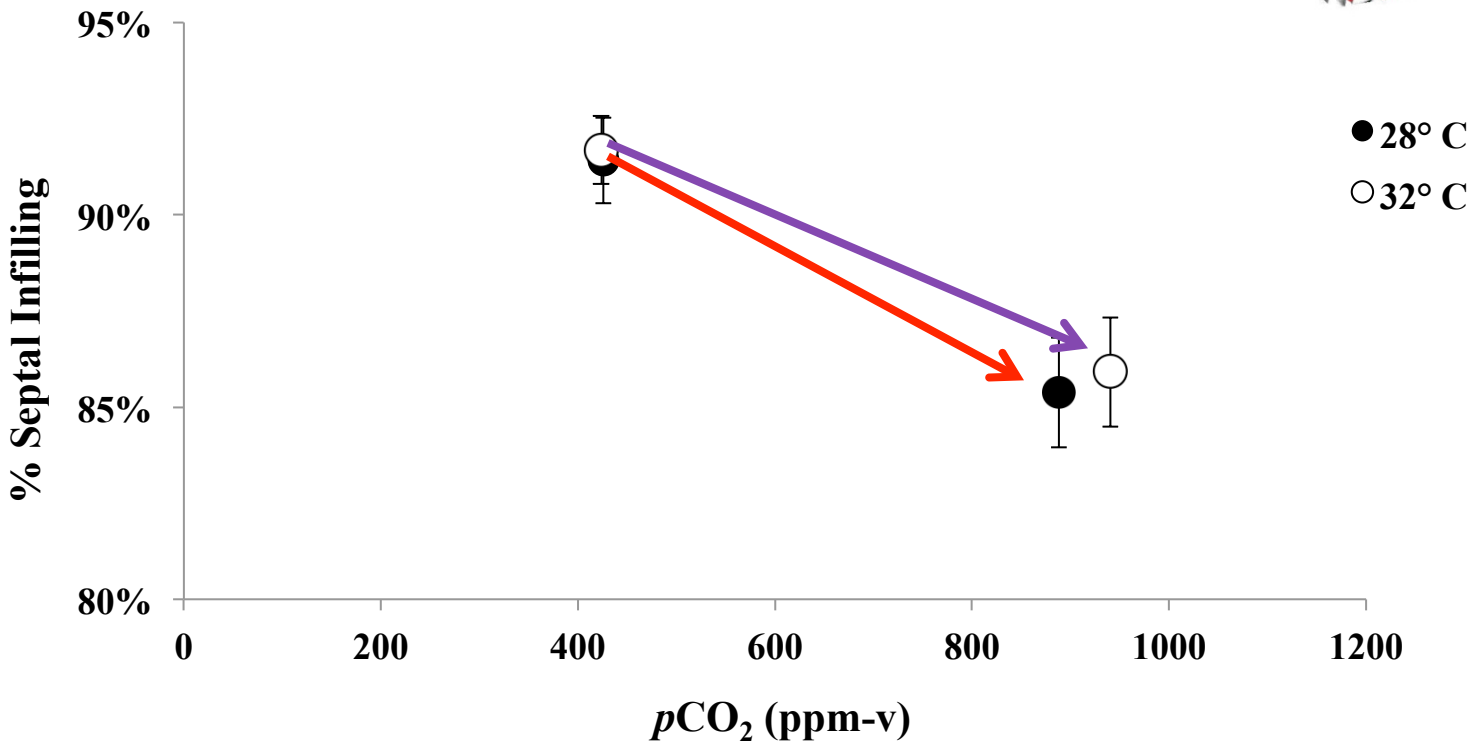
Septal Height: Temperature Effect



Results: Septal Morphology

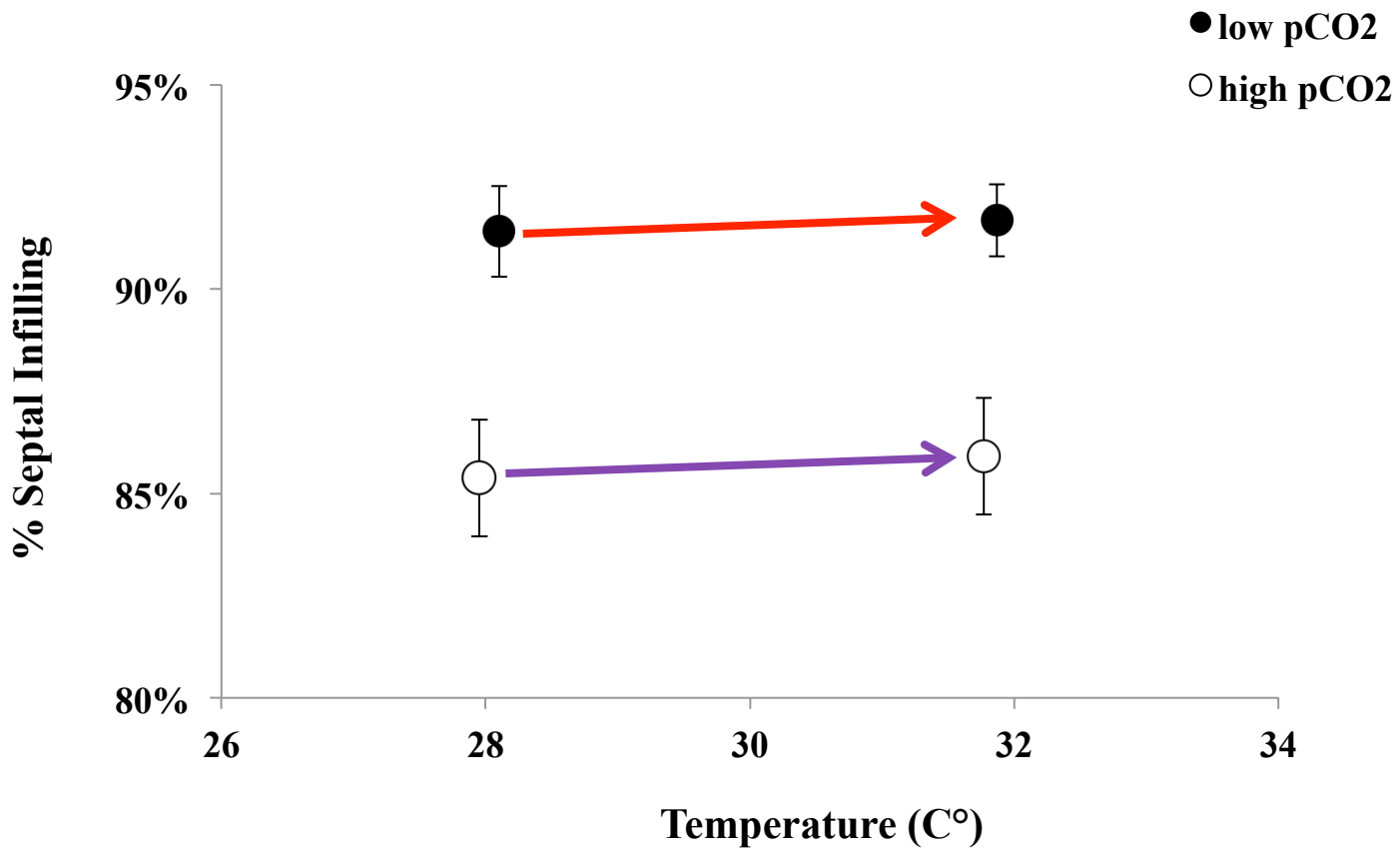
Septal Infilling: pCO_2 Effect

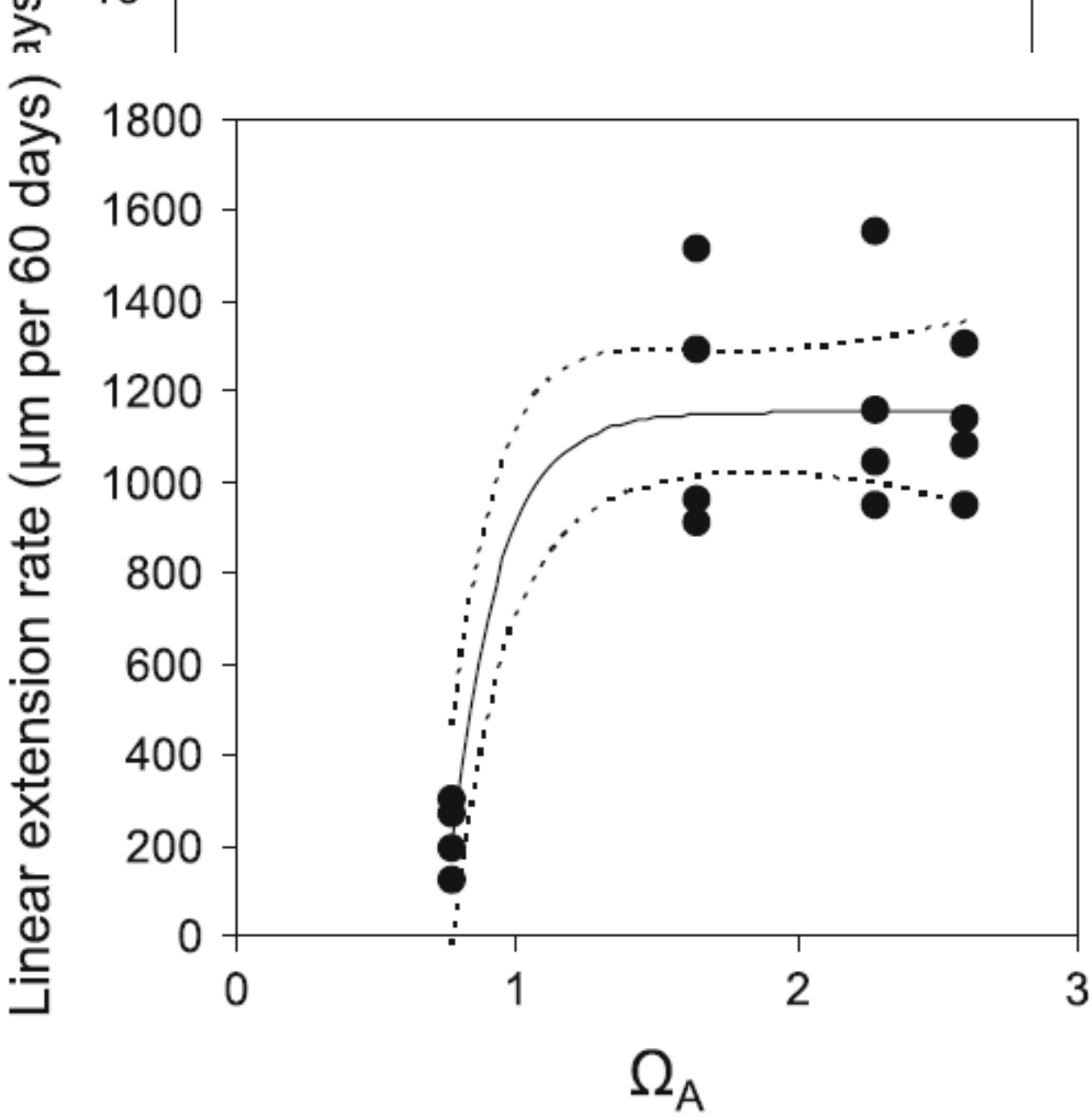




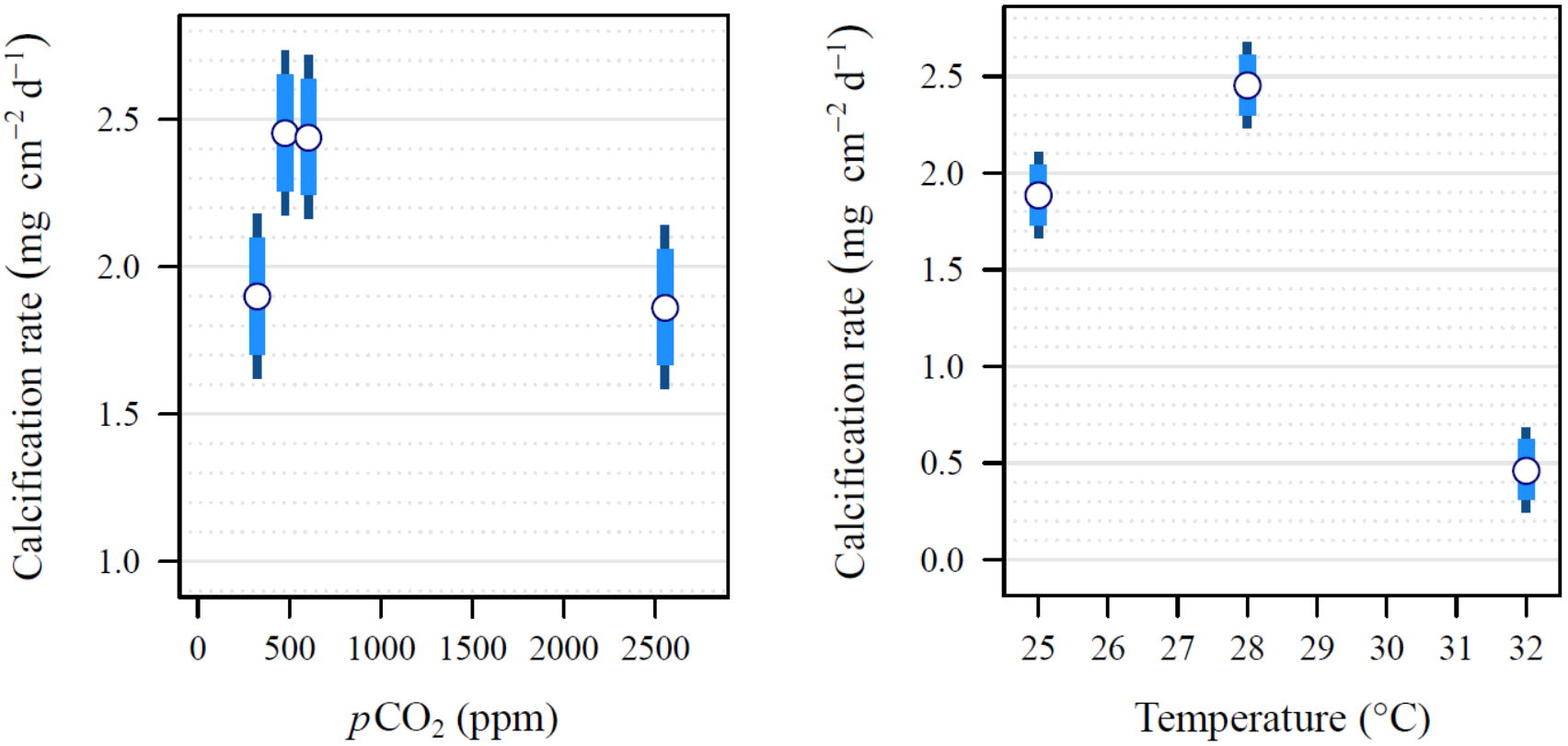
Results: Septal Morphology

Septal Infilling: Temperature Effect

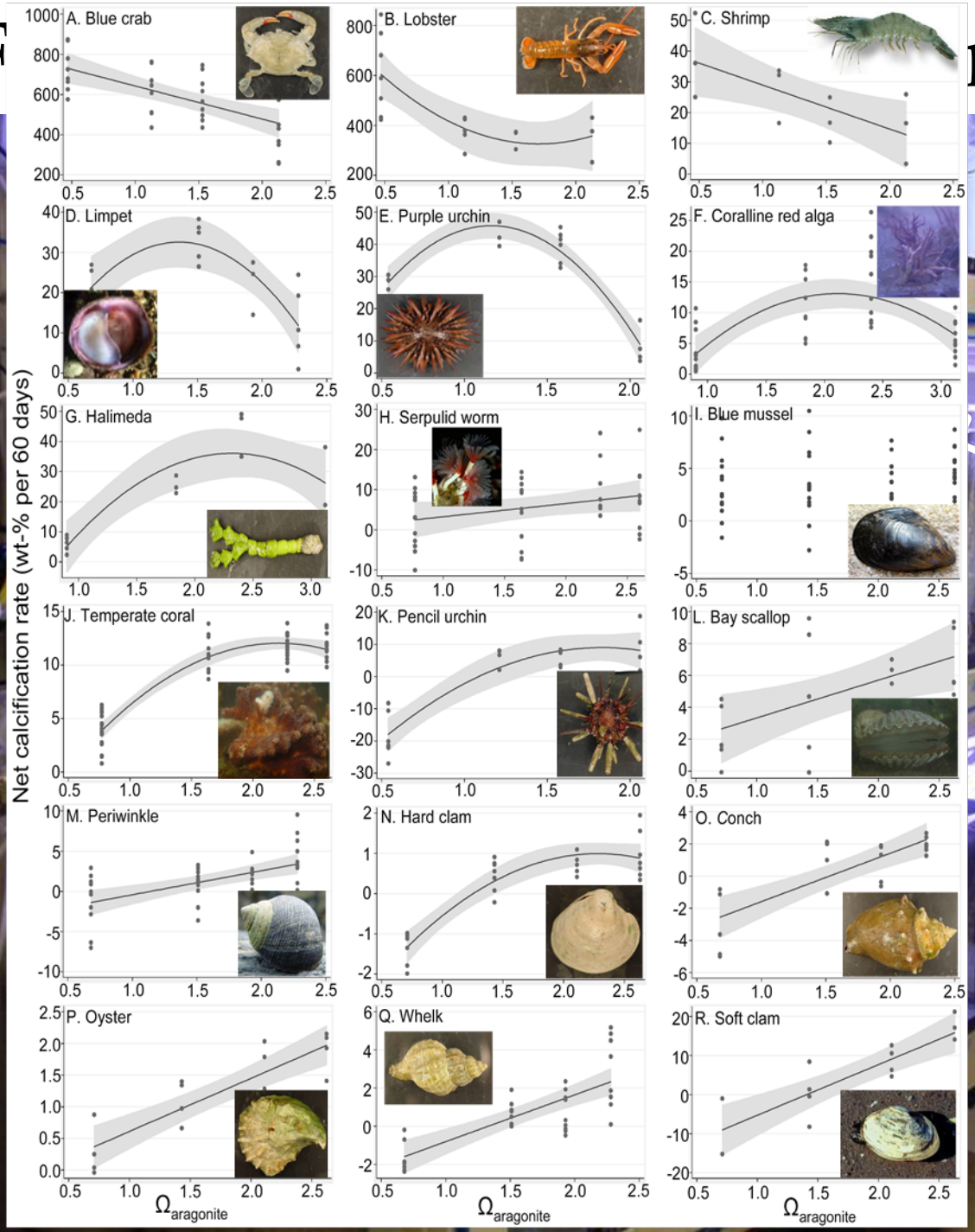




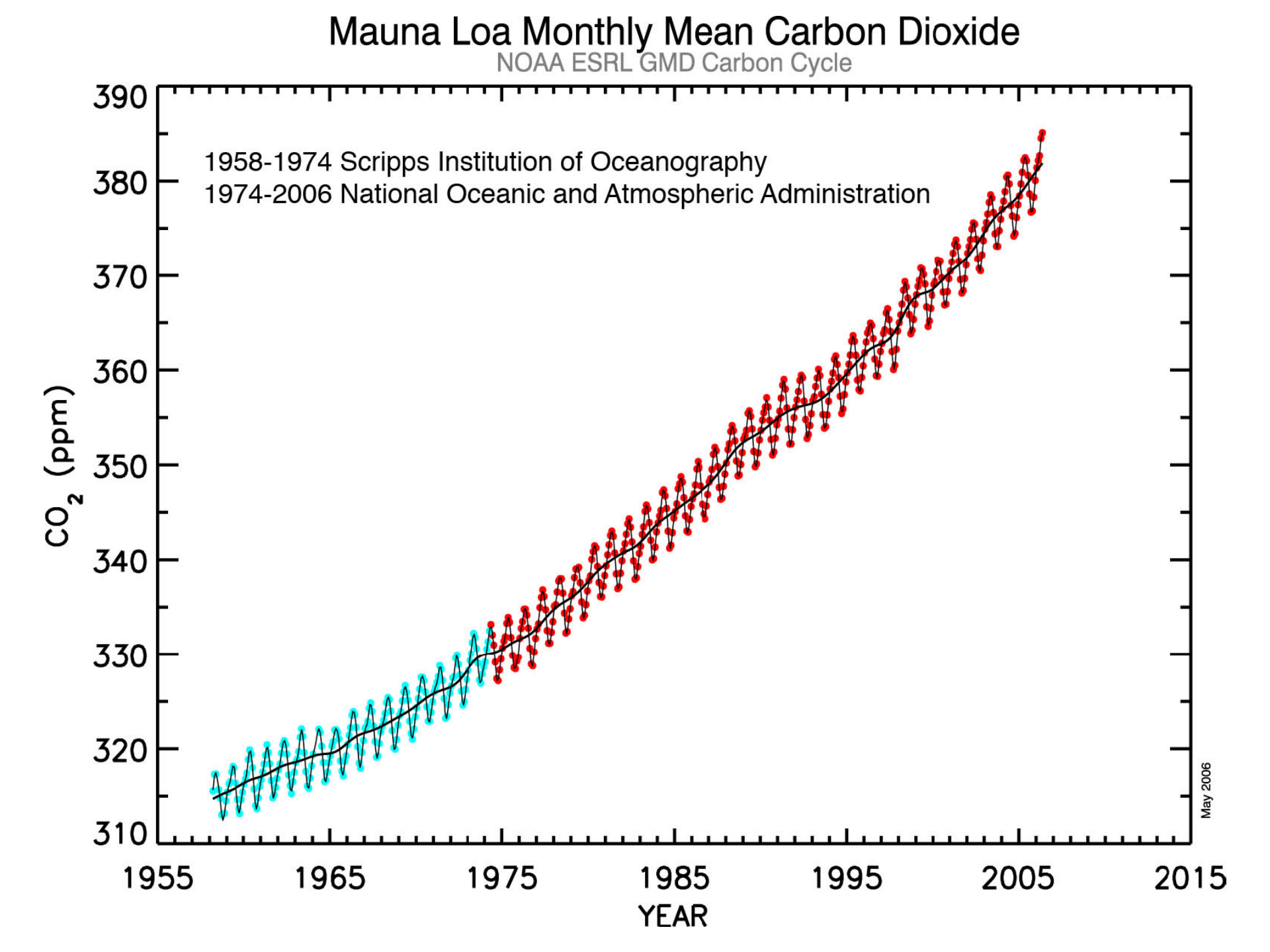
squares, and *closed squares* correspond to corals reared under Ω_A of

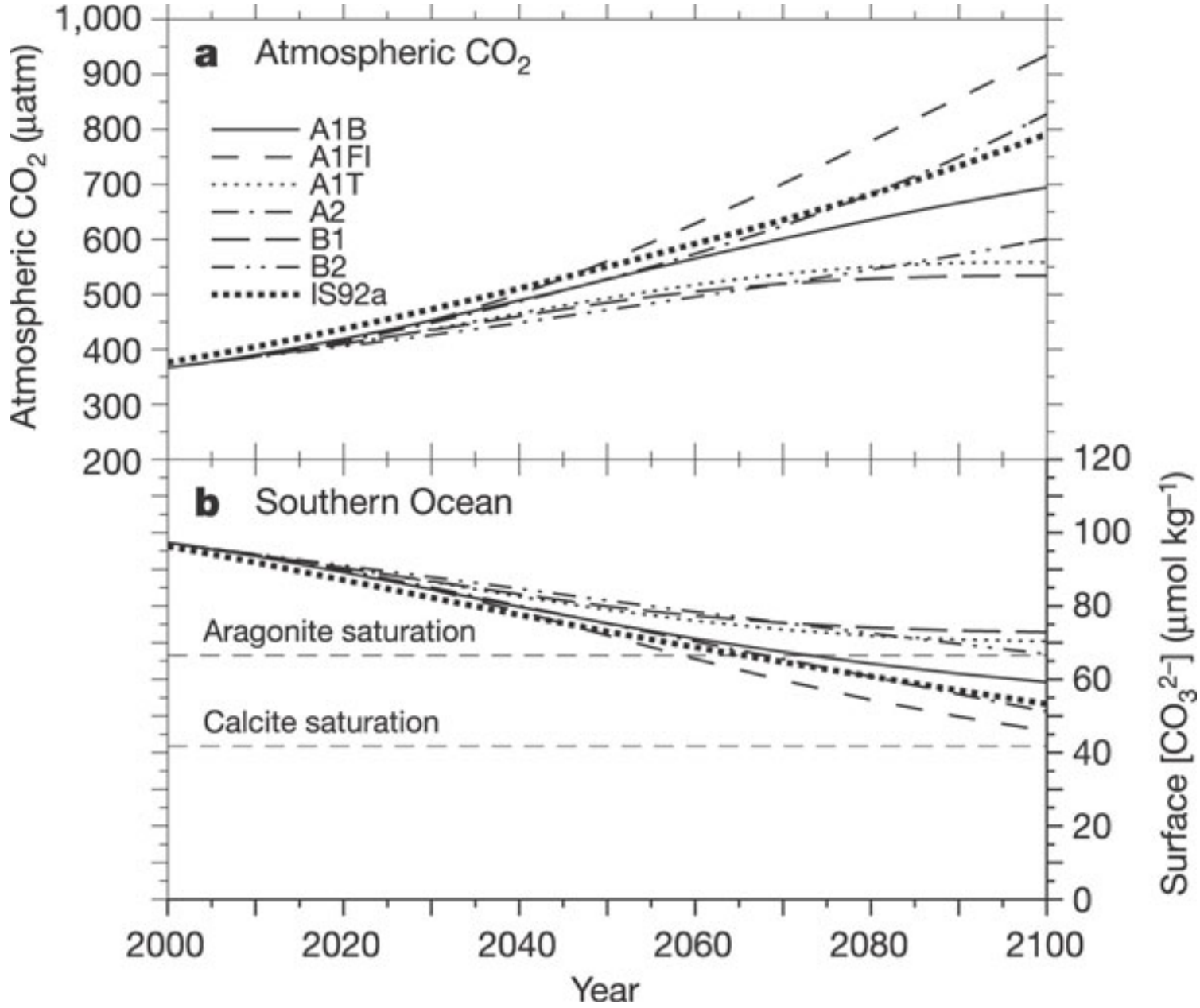

Calcification rate (mg cm^{-2} d^{-1})
2.5
2.0
1.5
1.0
0
500
1000
1500
2000
2500
pCO_2 (ppm)
Calcification rate (mg cm^{-2} d^{-1})
2.5
2.0
1.5
1.0
0.5
0.0
25
26
27
28
29
30
31
32
Temperature (°C)

F n

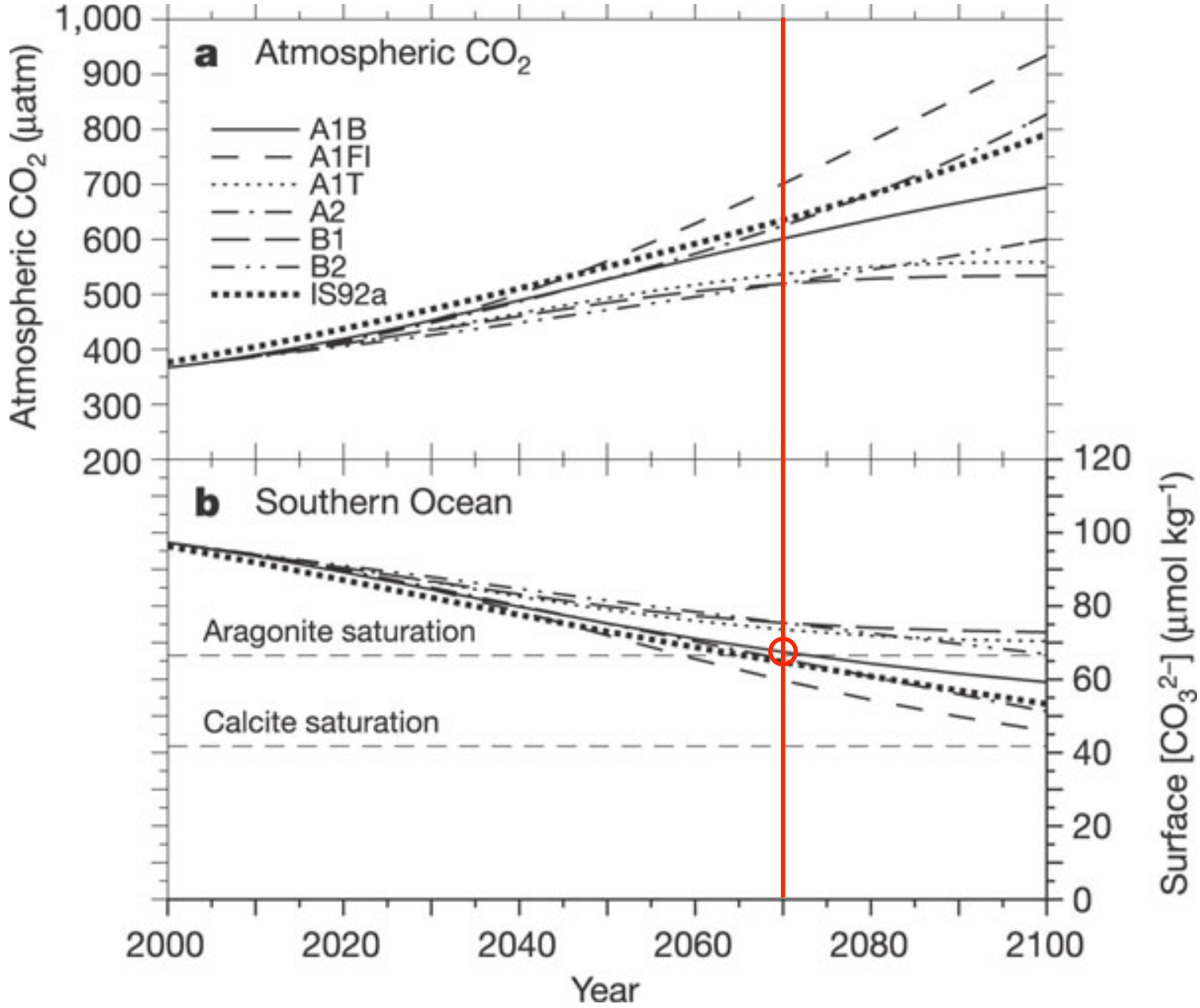


Ries, Cohen and McCorkle, 2009, Geology


Mauna Loa Monthly Mean Carbon Dioxide
NOAA ESRL GMD Carbon Cycle
1958-1974 Scripps Institution of Oceanography
1974-2006 National Oceanic and Atmospheric Administration
CO2 (ppm)
390
380
370
360
350
340
330
320
310
1955
1965
1975
1985
1995
2005
2015
YEAR
May 2006



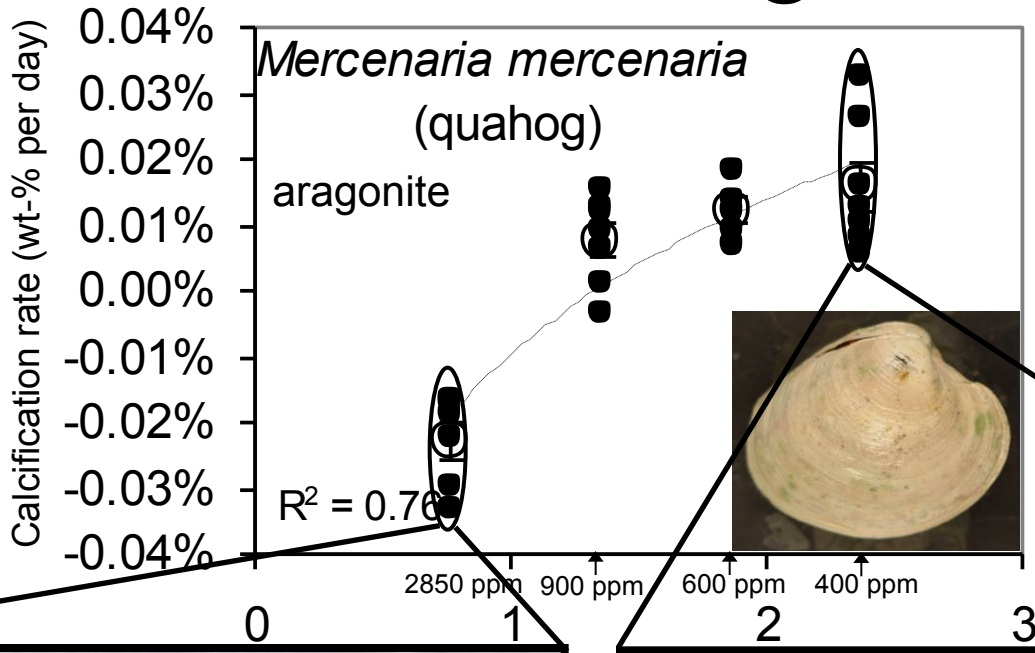
Orr et al, 2005

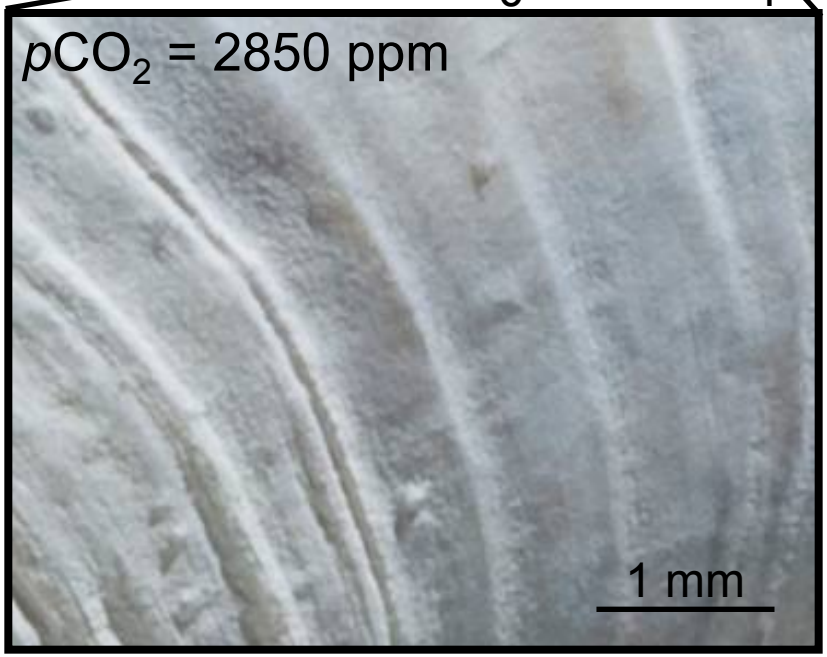


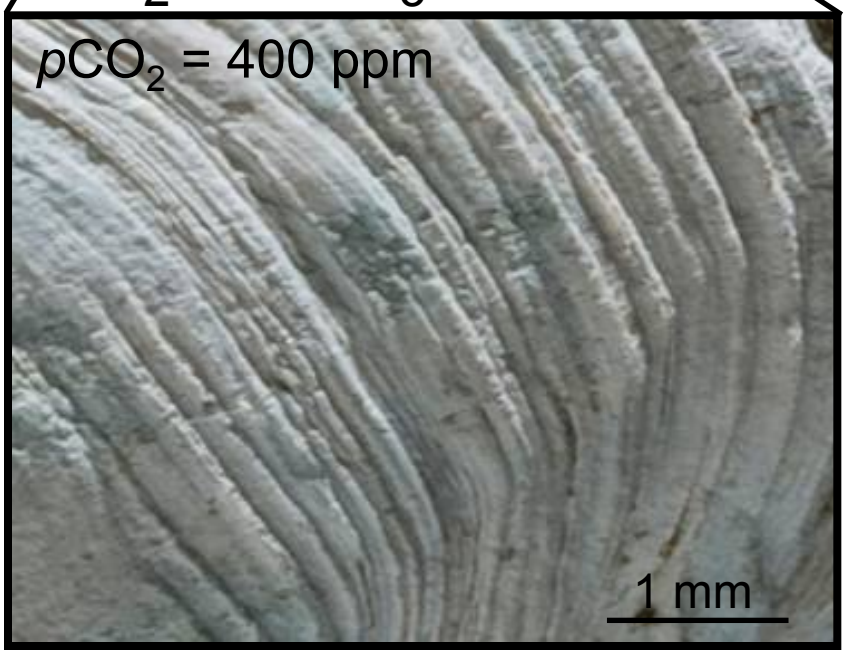
Orr et al, 2005

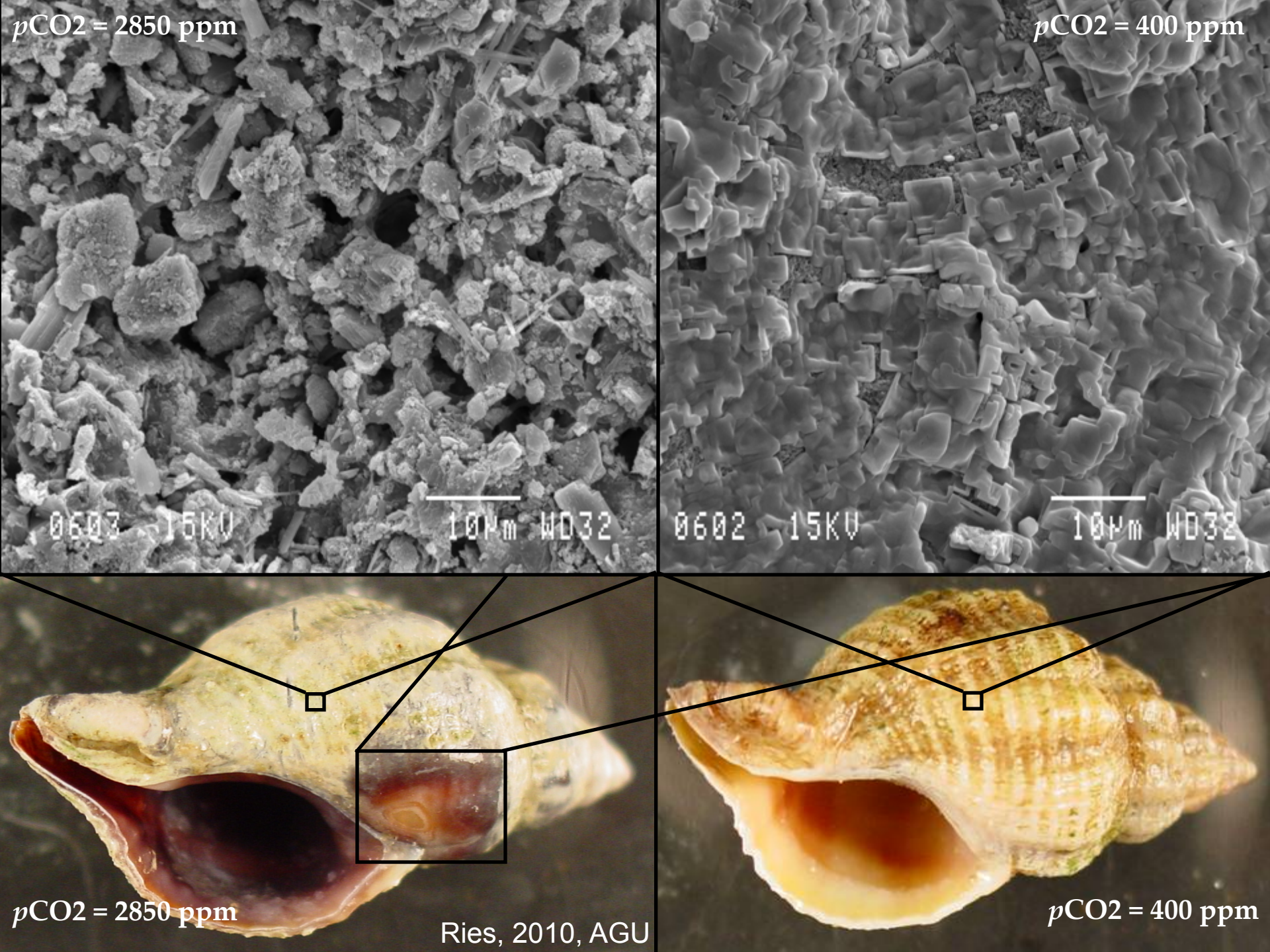
Justin B. Ries

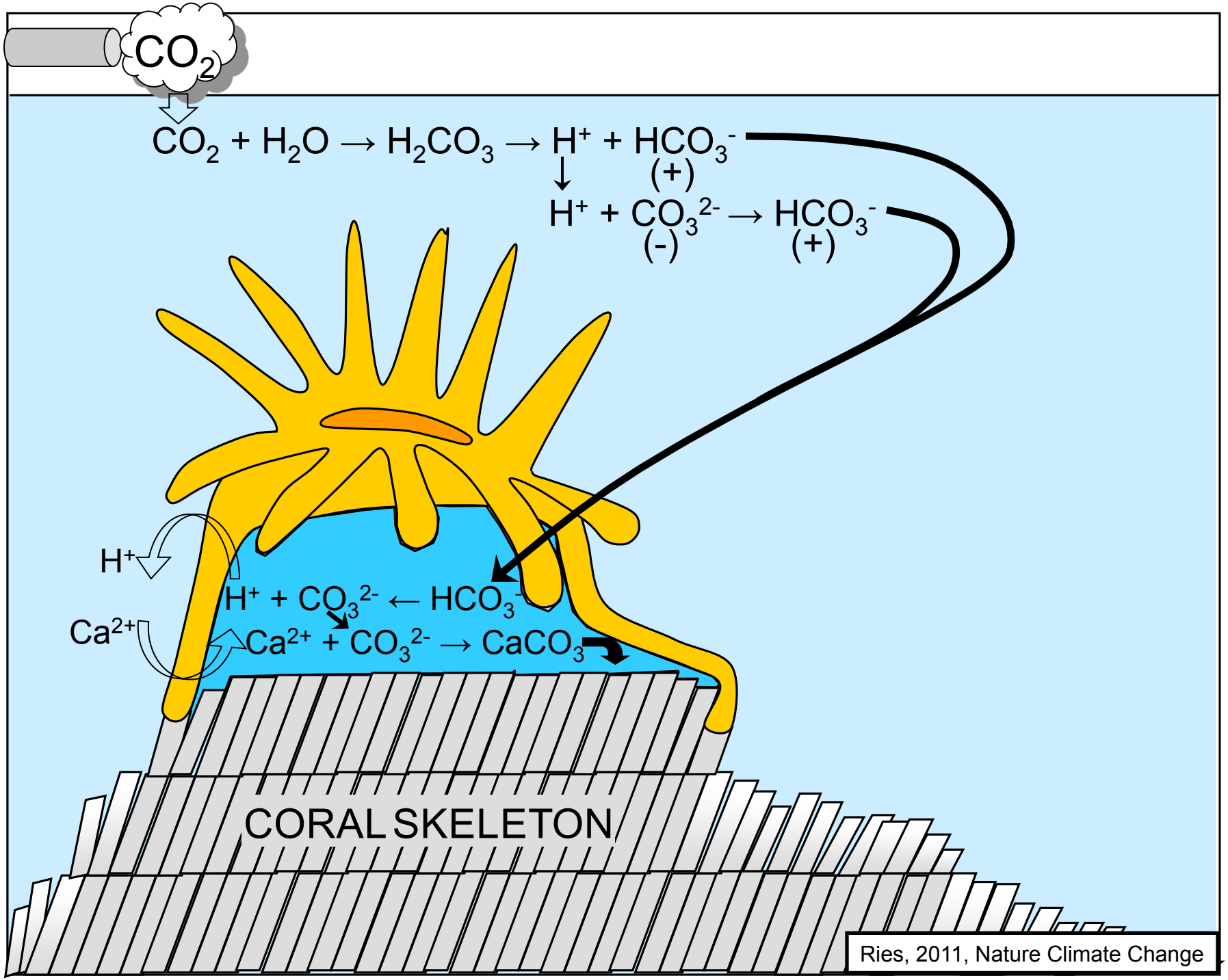
Bivalvia - aragonitic



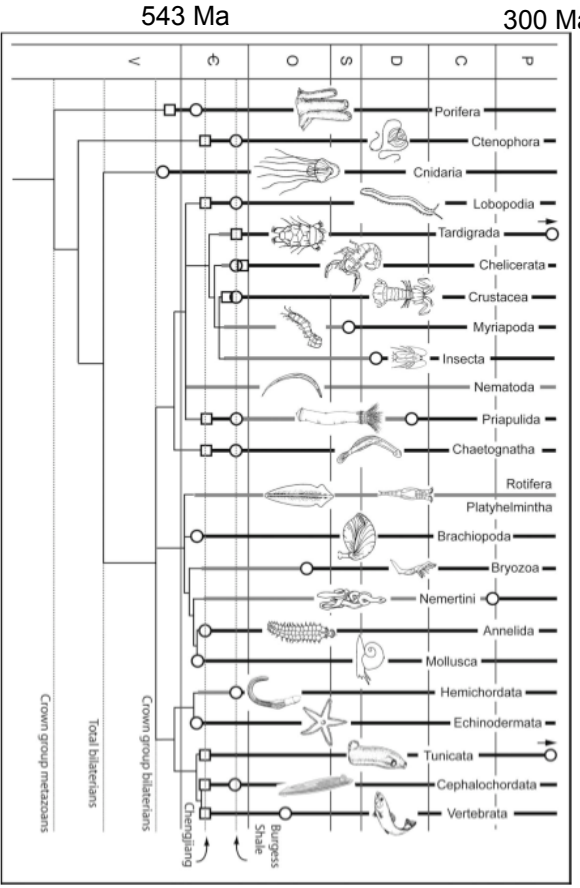


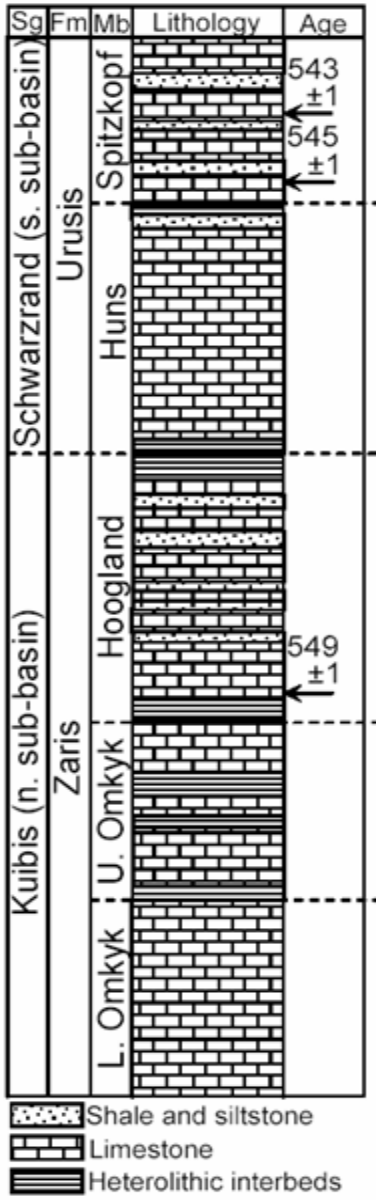


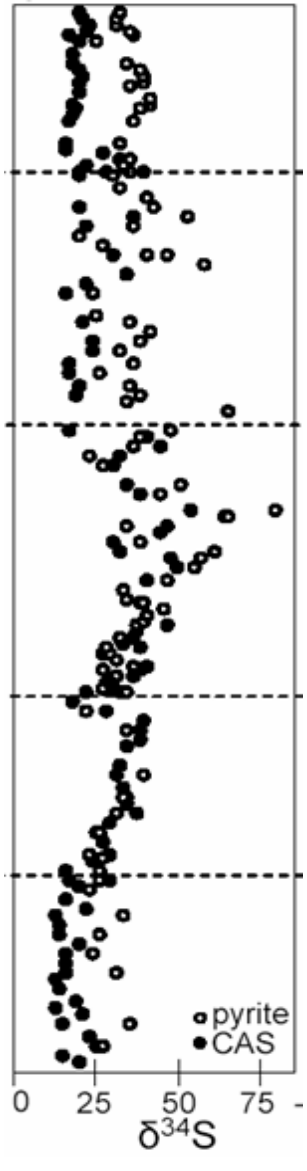

pCO2 = 2850 ppm
0603 15KV 10µm WD32
pCO2 = 400 ppm
0602 15KV 10µm WD32
pCO2 = 2850 ppm
pCO2 = 400 ppm
Ries, 2010, AGU

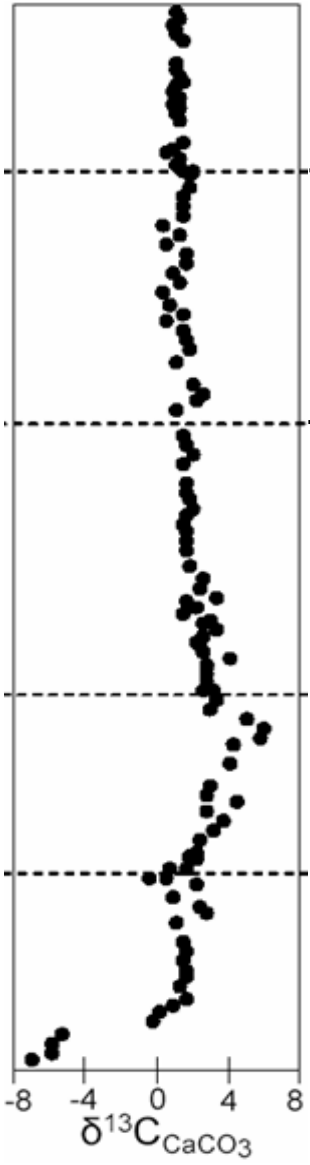

CO_2
$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$
(+)
$H^+ + CO_3^{2-} \rightarrow HCO_3^-$
(-)
(+)
H^+
Ca^{2+}
$H^+ + CO_3^{2-} \leftarrow HCO_3^-$
$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$
CORAL SKELETON
Ries, 2011, Nature Climate Change

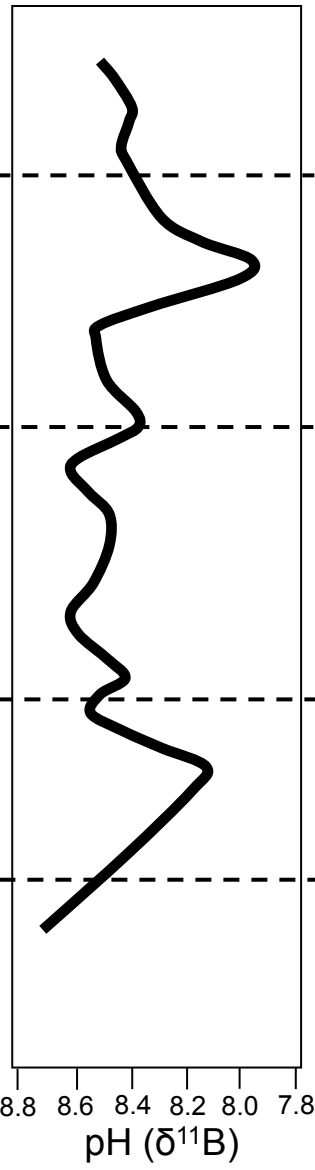
Ocean acidification in the deep past





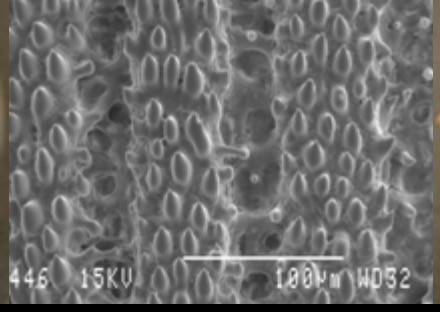


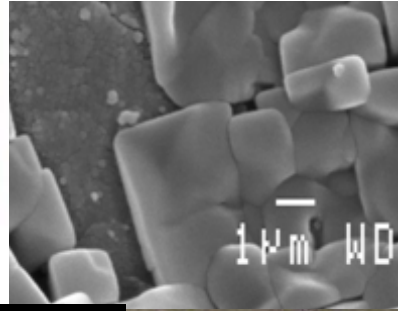




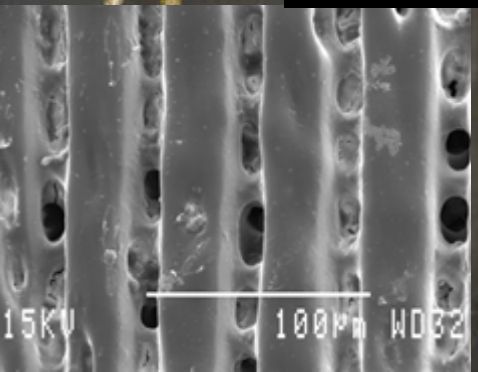
Funding: Petroleum Research Fund grant 50214-DNI8

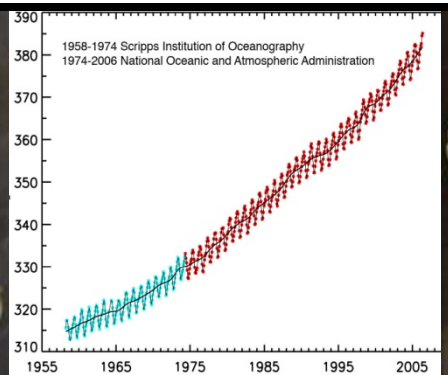
(Ries, Geology, 2009)



446 15KV
100µm WD32

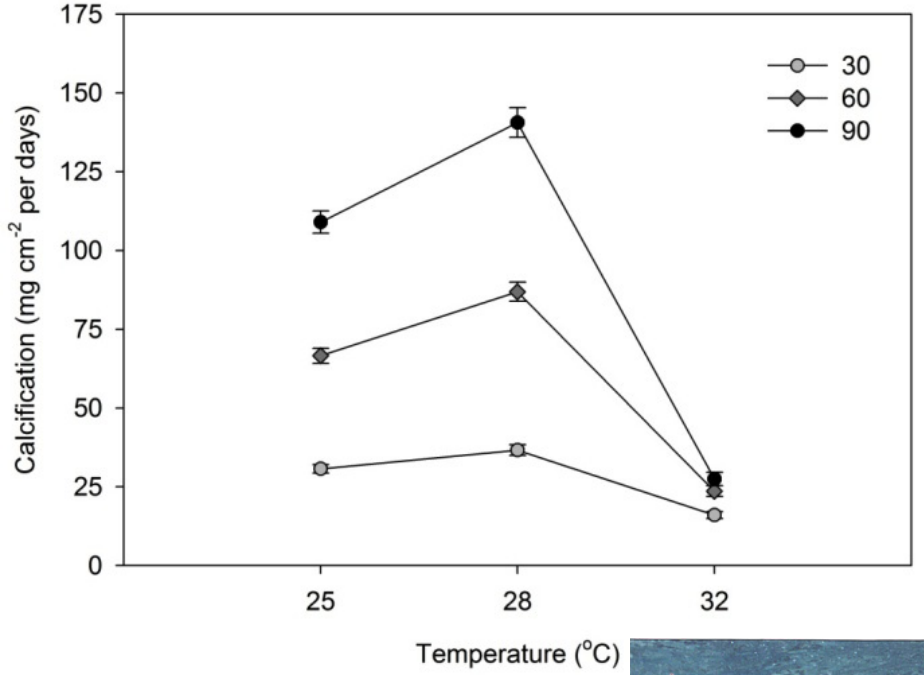


1µm WD

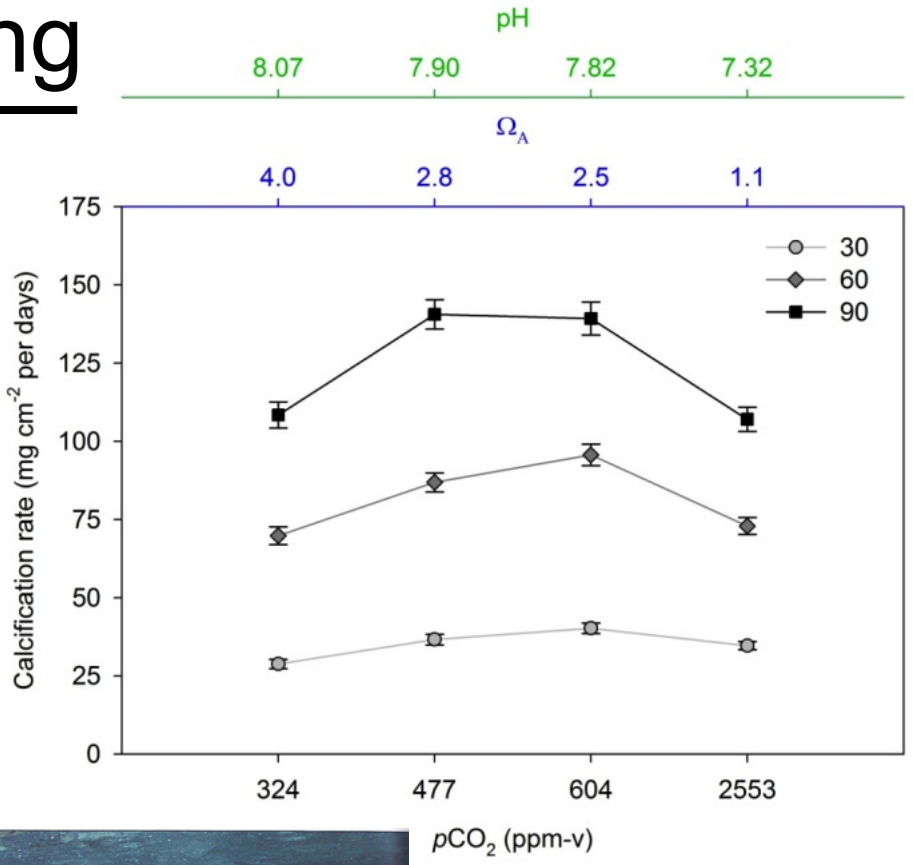



Justin B. Ries
Northeastern University
16 June 2014

15KV
100µm WD32


1958-1974 Scripps Institution of Oceanography
1974-2006 National Oceanic and Atmospheric Administration
390
380
370
360
350
340
330
320
310
1955
1965
1975
1985
1995
2005

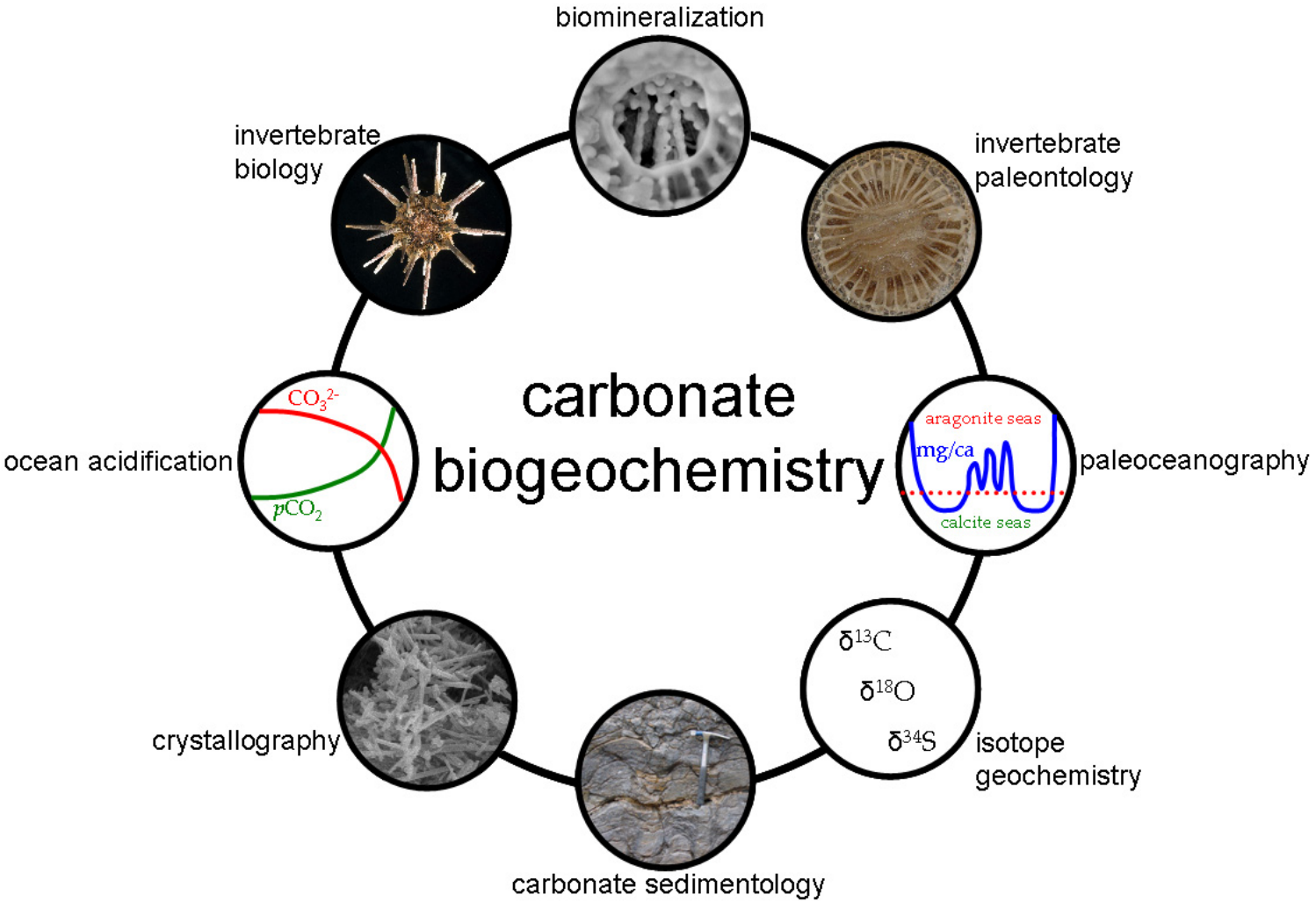
Impact of OA/warming



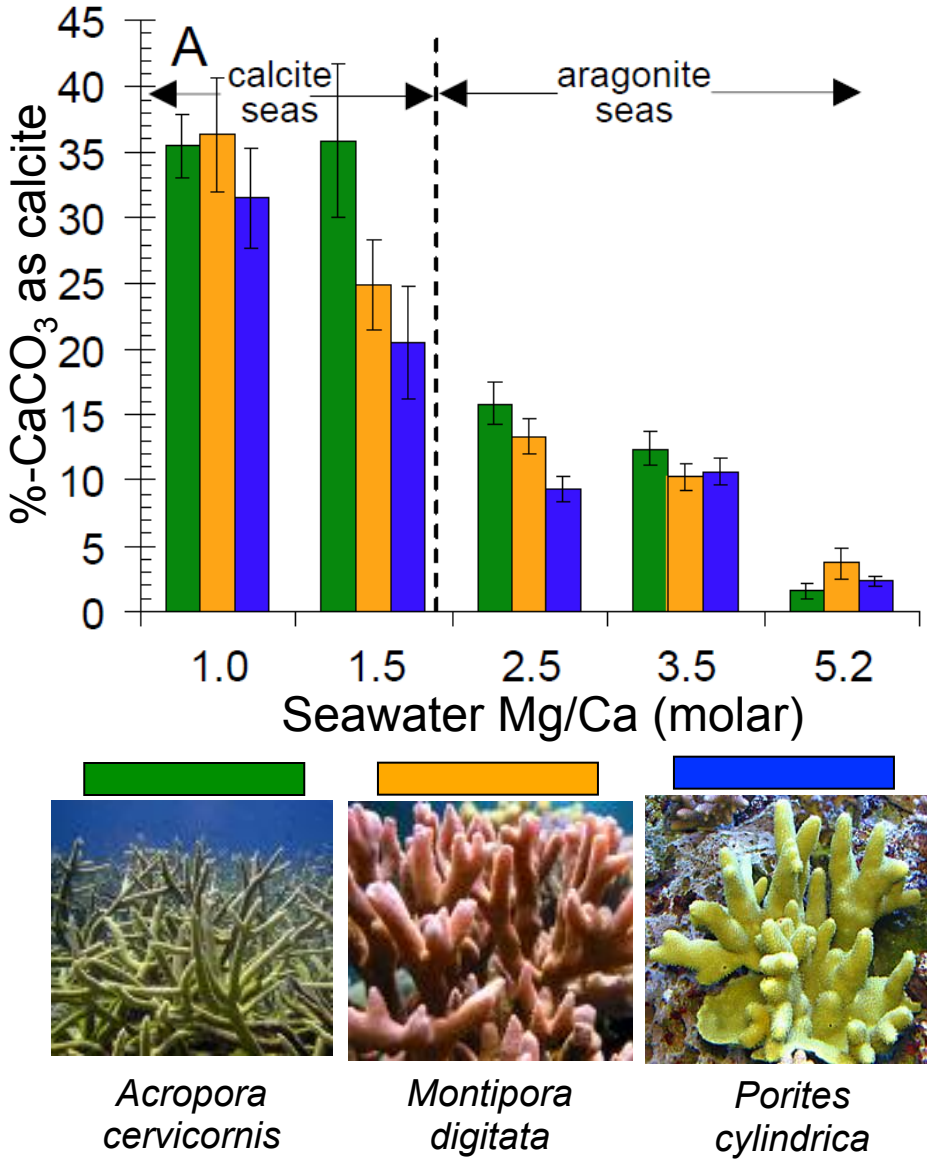


Castillo, Ries, Bruno & Westfield, in review

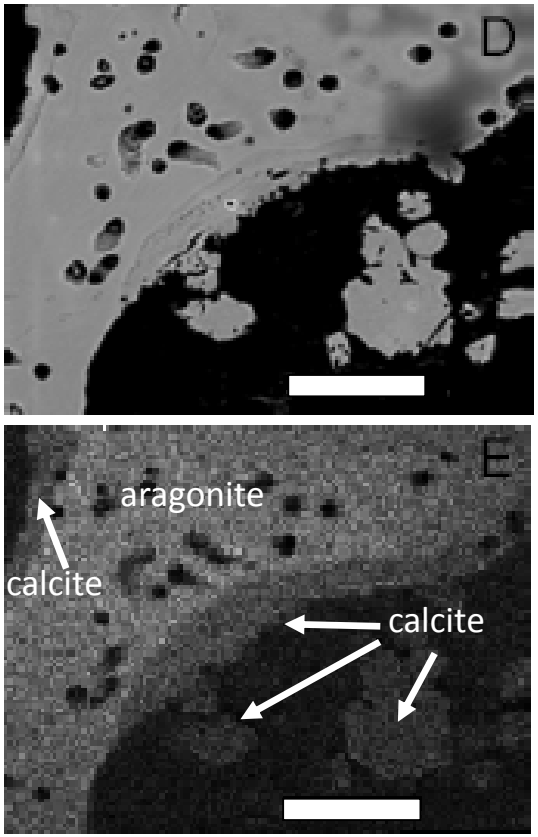
the Ries Lab


biomineralization
invertebrate biology
invertebrate paleontology
carbonate biogeochemistry
ocean acidification
CO_3^{2-}
pCO_2
aragonite seas
mg/ca
calcite seas
paleoceanography
crystallography
$\delta^{13}C$
$\delta^{18}O$
$\delta^{34}S$
isotope geochemistry
carbonate sedimentology

Impact of seawater Mg/Ca

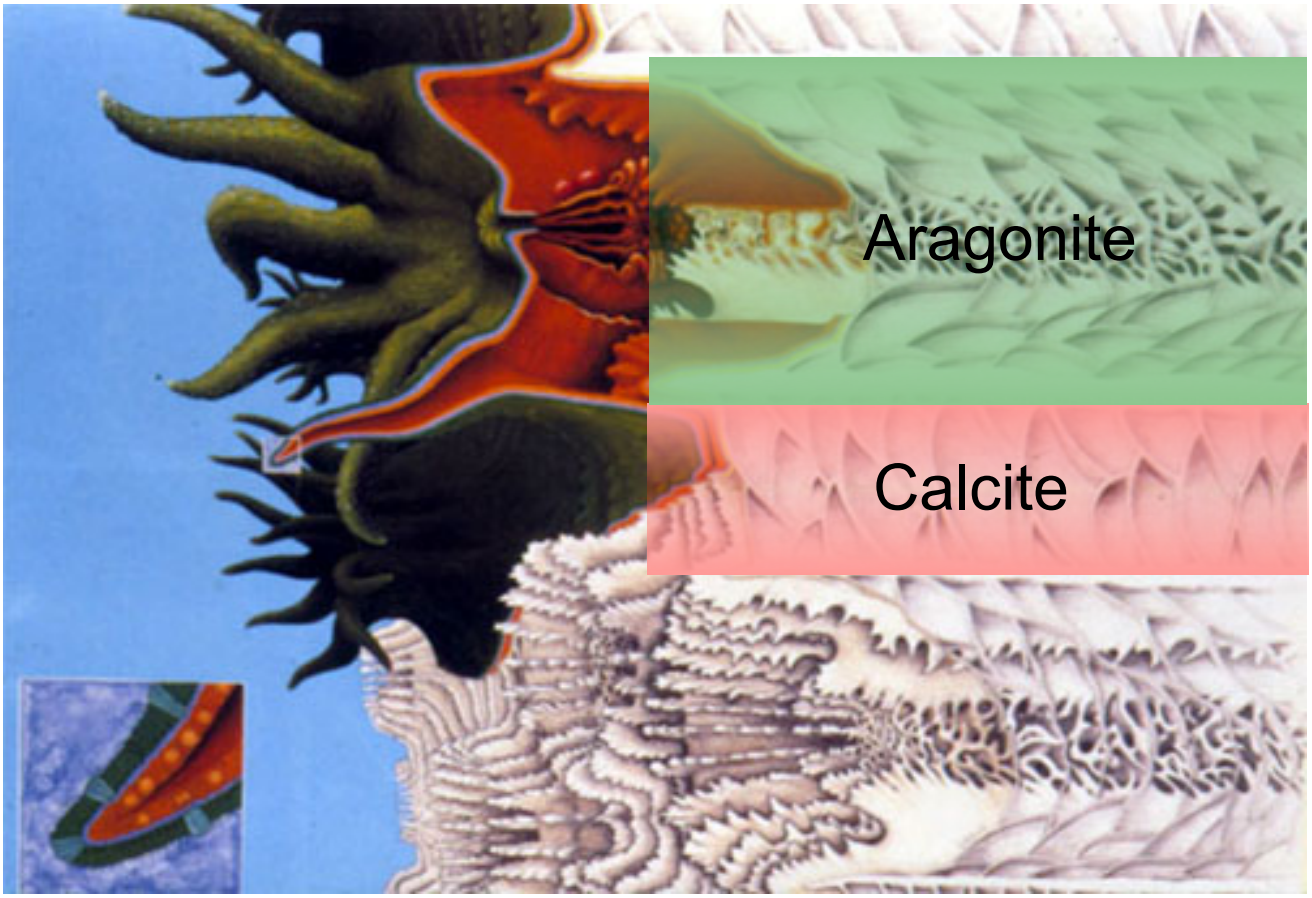


Porites cylindrica



Ries et al., 2006,

Veron, 1986



Veron, 1986