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Planktonic calcifiers and ocean acidification

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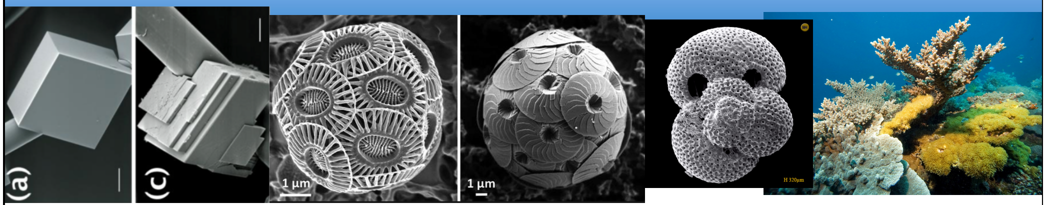
What is the presentation about?

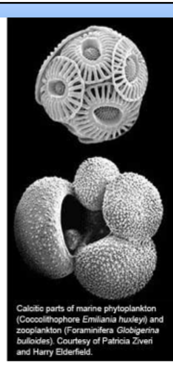
- Why planktonic calcifiers? Calcification mode evolution in high CO_2
- Timing of carbon cycle
- Main planktonic calcifiers, from laboratory experiment to field observation
- How is calcification measured? (e.g. radioisotopes (^{45}Ca, ^{14}C)
- Coccolithophores (phytoplankton)
- Foraminifera (zooplankton)
- Pteropods (zooplankton)

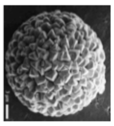
What is calcification?

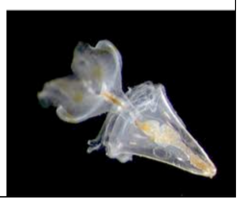


1. $CaCO_3$ can be precipitated by biological or inorganic processes, in terrestrial, freshwater, and marine environments.
2. The large majority of marine carbonate production is of biogenic origin.
3. Calcification: "A process by which organisms precipitate calcium carbonate"

Why planktonic calcifiers?







1. Major global calcium carbonate producers
2. At the base of the food web
3. Coccolithophores, foraminifera and pteropods largely driving pelagic carbonate production
4. different forms of $CaCO_3$ such as aragonite or low Mg calcite
5. Shell mass and morphology can relate to carbonate export, morphogenesis,

OA and calcification

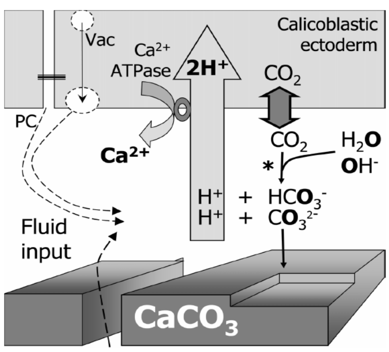
High CO_2 ocean → OA → a general reduction of marine calcification (physiology) and carbonate production (carbon cycle)

it is still unknown how large such a potential reduction in calcification will be in the future and what will be the effects on the marine community dynamics and marine biogeochemistry.

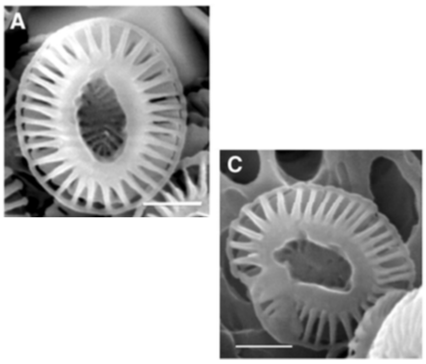
Why should ocean acidification impact calcification?

1.Direct shifts in acid-base balance (pH, ionic composition) of intracellular fluids that compromise calcification process

Cohen and McConnaughey, 2003



The coral controls the composition of the ECM



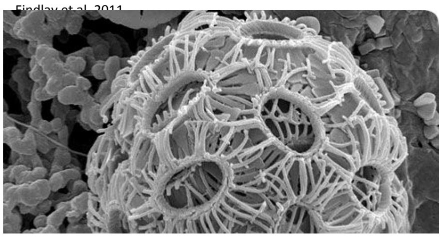
MALFORMATION

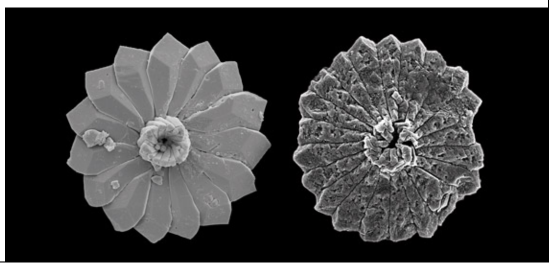
calcification inhibited by protons (H+)

Why should ocean acidification impact calcification?

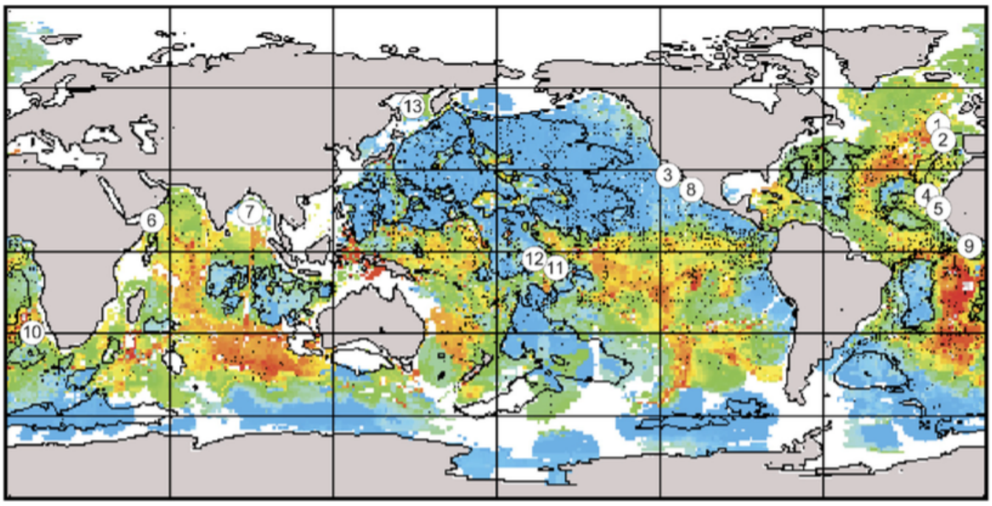
2. Enhanced dissolution in undersaturated conditions
e.g. dissolution of "dead" structures compared to "live"

Findlay et al. 2011





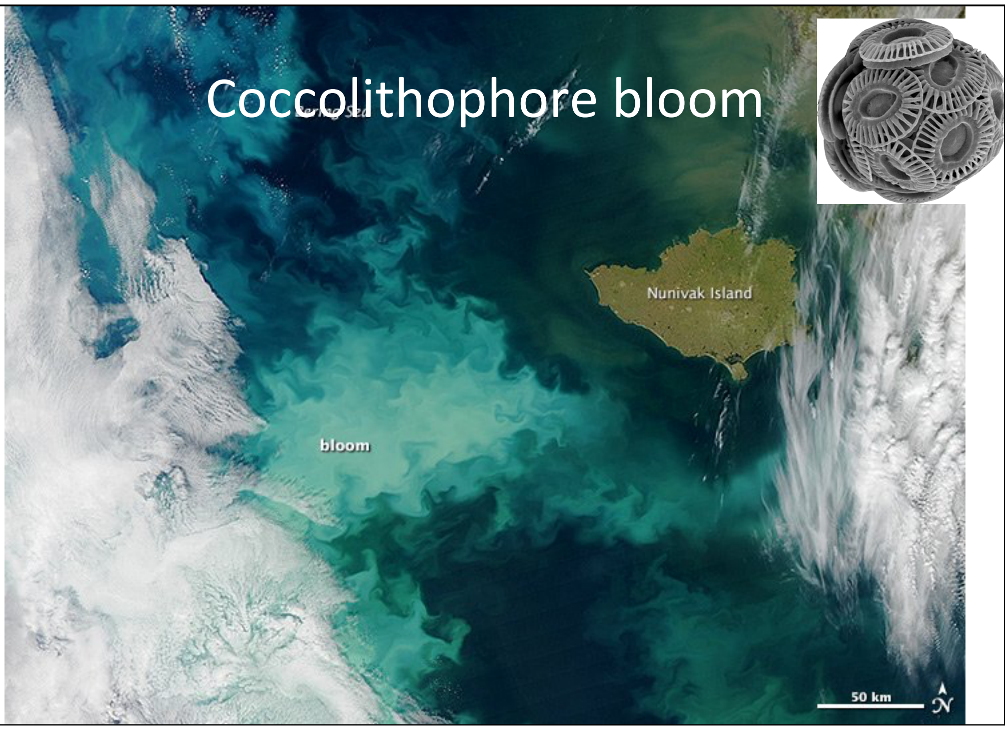
- If calcification is impacted .. . why should we care about planktonic calcifiers?

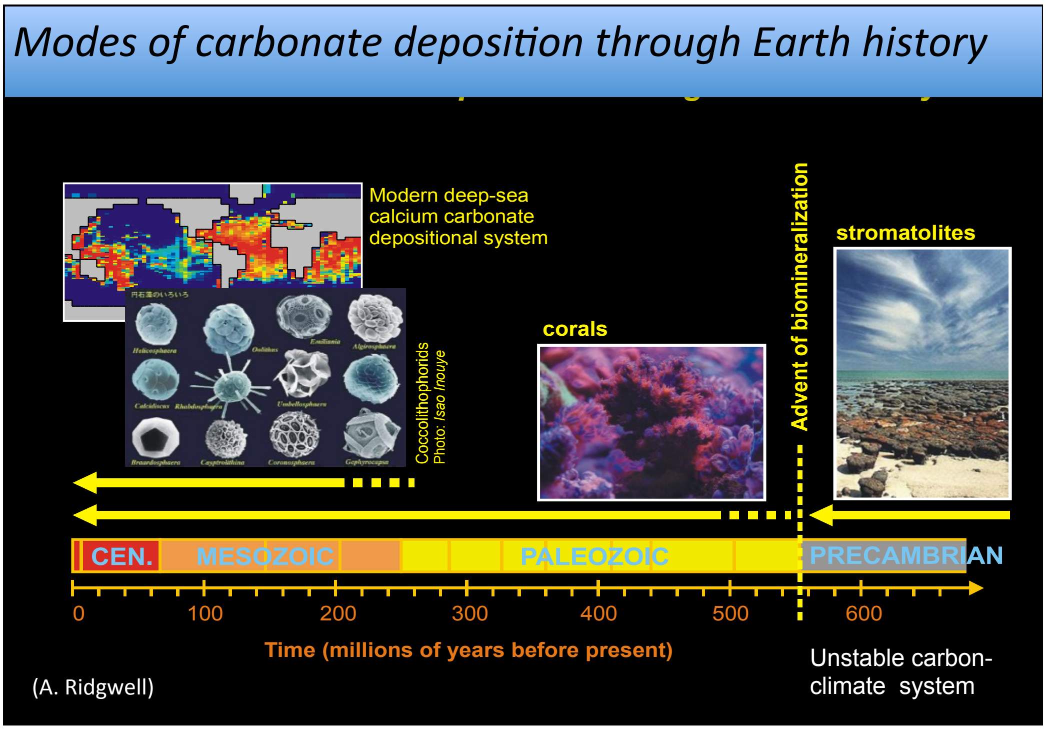


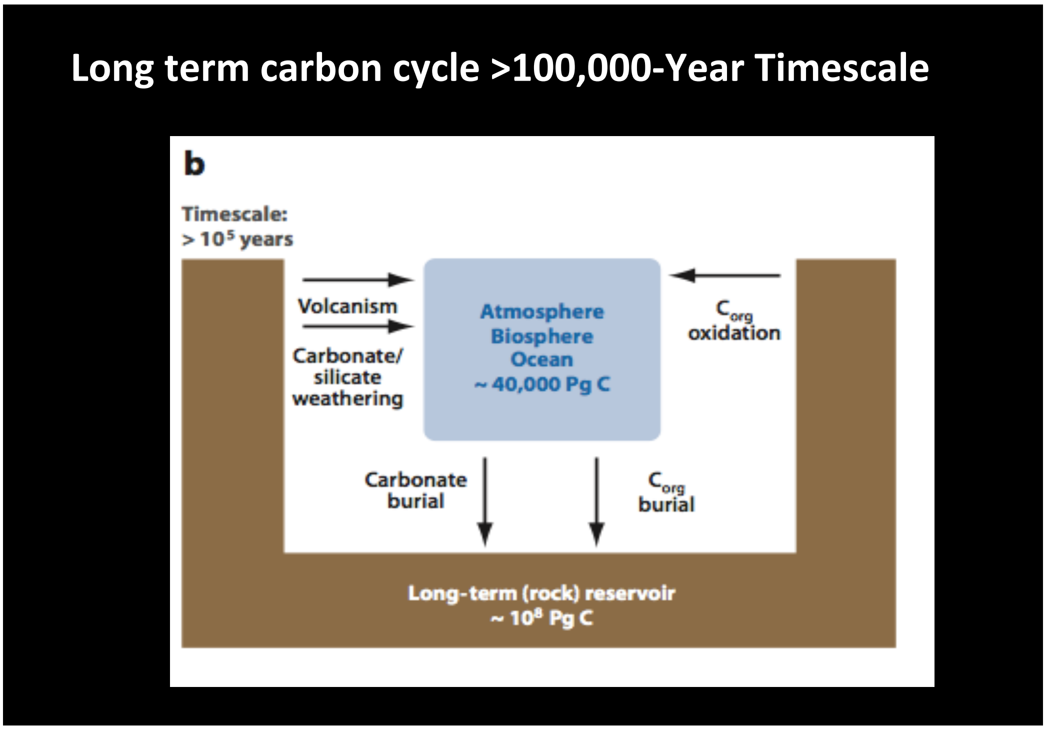
distribution of sedimentary calcite

Ziveri et al. 2007; Archer and Maier-Reimer 1994

Coccolithophore bloom




Modes of carbonate deposition through Earth history
Modern deep-sea calcium carbonate depositional system
Coccolithophorids
Photo: Isao Inouye
corals
Advent of biomineralization
stromatolites
CEN.
MESOZOIC
PALEOZOIC
PRECAMBRIAN
0
100
200
300
400
500
600
Time (millions of years before present)
Unstable carbon-climate system
(A. Ridgwell)

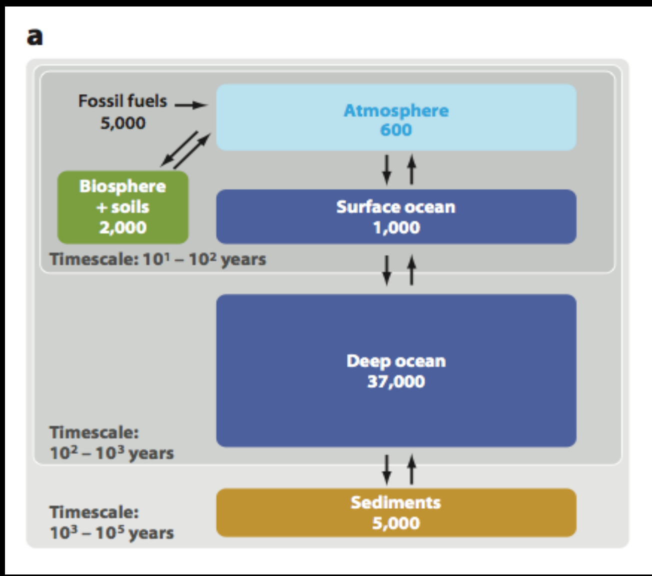

Long term carbon cycle >100,000-Year Timescale
b
Timescale:
> 10^5 years
Volcanism
Carbonate/ silicate weathering
Atmosphere
Biosphere
Ocean
~ 40,000 Pg C
C_{org} oxidation
Carbonate burial
C_{org} burial
Long-term (rock) reservoir
~ 10^8 Pg C

Surface carbon cycle and the ocean timescale

10-100 years

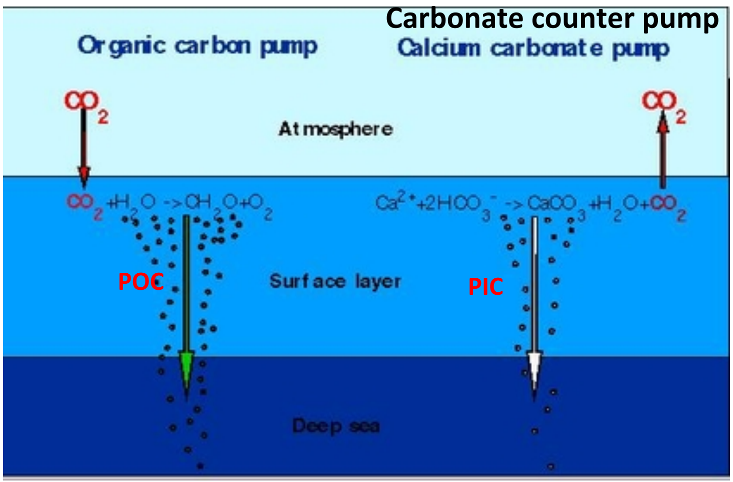
1000 years

1000 – 100.000 years



Zeebe, 2012

Why are they important?
Calcification and CO_2



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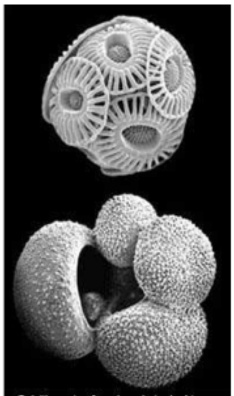
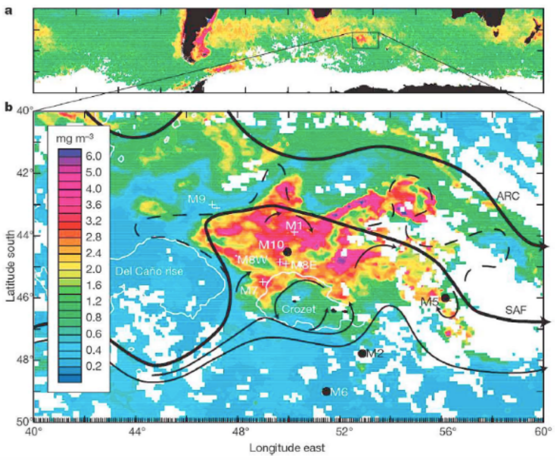
Carbonate counter pump stimulated by natural iron fertilization in the Polar Frontal Zone

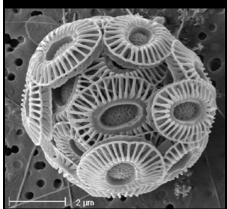
Ian Salter[1,2]*, Ralf Schiebel[3], Patrizia Ziveri[4,5], Aurore Movellan[3], Richard Lampitt[6] and George A. Wolff[7]

Production and flux of carbonate in naturally iron-fertilized waters reduces the overall amount of CO2 transferred to the deep ocean by 6–32%, compared to 1–4% at the non-fertilized site.



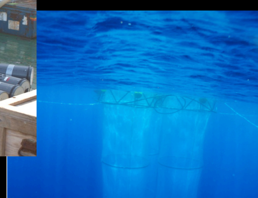
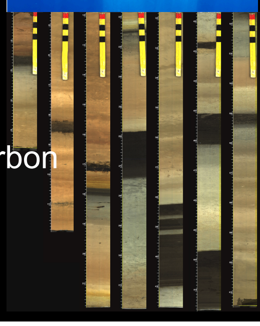
Calcitic parts of marine phytoplankton (Coccolithophore *Emiliania huxleyi*) and zooplankton (Foraminifera *Globigerina bulloides*). Courtesy of Patrizia Ziveri and Harry Elderfield.









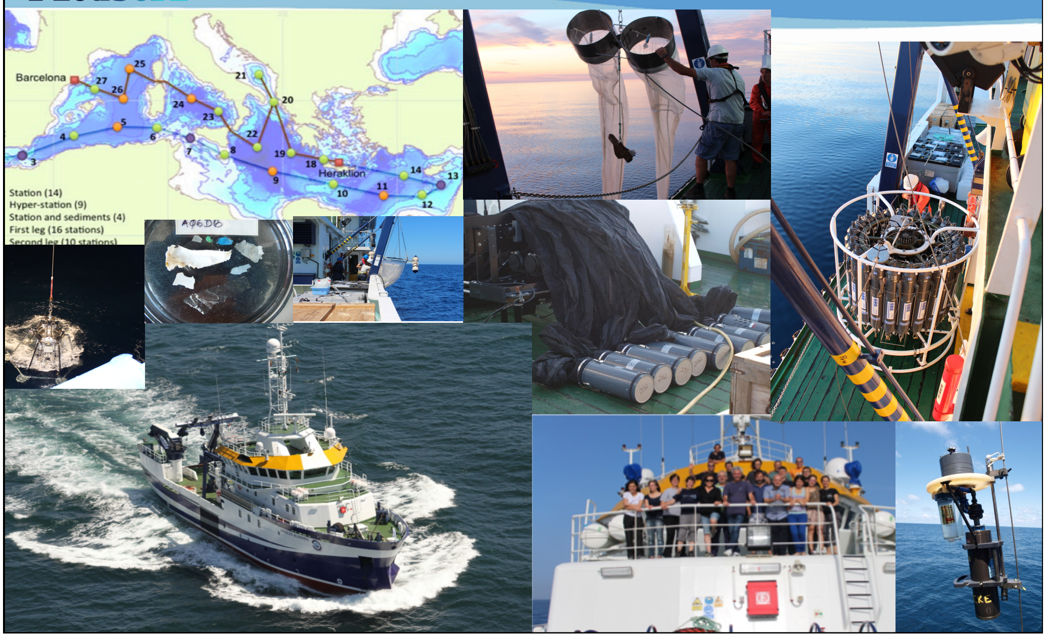
Investigating the relationship between planktonic organism performance under changing environmental conditions

- base of food webs
- ocean productivity, fisheries and the export of carbon
- carbon cycle and seawater carbonat chemistry

OA: from lab experiments to field observations

MedSeA

2013 oceanographic cruise



..but how to we measure calcification?

How to measure calcification (amount of $CaCO_3$ or particulate inorganic carbon PIC)

$2HCO^{-3} + Ca^{2+} \rightarrow CO_2 + CaCO_3 + H_2O$

Summary of techniques

- Geological approach
- Sedimentological approach
- Alkalinity Anomaly Technique
- Radioisotopes (^{45}Ca, ^{14}C, ^{3}H-tetracycline)
- Changes in particulate calcium content
- Change in calcium concentration
- pH-O_2
- X-ray analysis
- Buoyant weight
- “Biological” approach
- Changes in Particulate Inorganic Carbon content
- Molecular tools

Sedimentary record - Geological

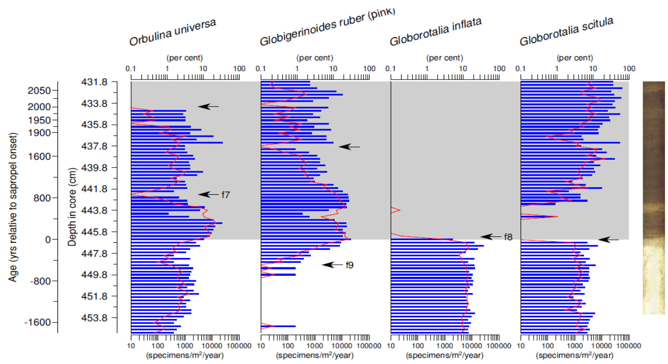
$CaCO_3$ accumulates in sediment over time giving an indication of rates of calcification.

Net accumulation of $CaCO_3$ is calculated by the thickness of the layer multiplied by the density, divided by the time increment (measured by radiocarbon dating)
Level: Community
Timescale: >10 years (in varves higher)
Pros: Provides integrated, long-term estimates

Turley et al. 2009

Sedimentary record – particle fluxes

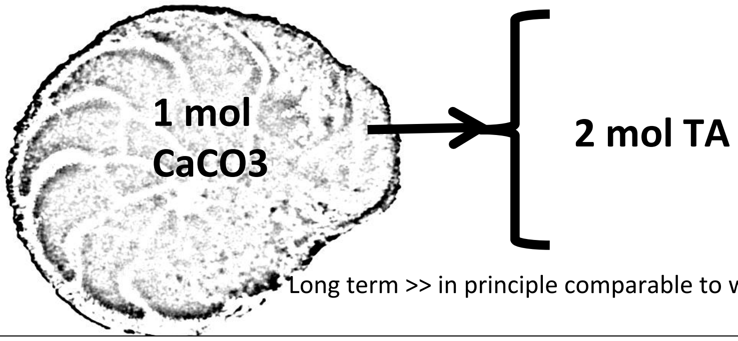
Calcified organisms accumulate within sediments. **Net calcification (?)** is measured using the percentage weight contribution in sedimentary skeletal components
Level: Community
Timescale: particle fluxes (week, months); sediments >10 years
Pros: Only needs sediment samples.
Cons: It is not clear what this approach measures, it does not account for advection terms



Weinkof et al. 2013

Alkalinity Anomaly Technique

Alkalinity is lowered by two equivalents for each mole of CaCO3 precipitated.
Net calcification is calculated by measuring the TA before and after an incubation period, and the ΔTA is scaled to ΔCaCO3 (i.e. calcification = 0.5xΔTA)
Level: Organisms and communities
Timescale: Hours to weeks
Pros: Very precise (1 SD = 3 µmol/kg or about 0.2%)
Cons: Needs discrete samples (but see Watanabe et al., 2004). A correction for changes in nutrients may be needed. Need to enclose or know residence time.



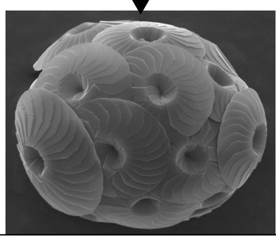
Long term >> in principle comparable to weight method

Uptake of a radio-isotope

Short term > incubation time typically minutes to hours

>> "snapshot" of a particular physiological state

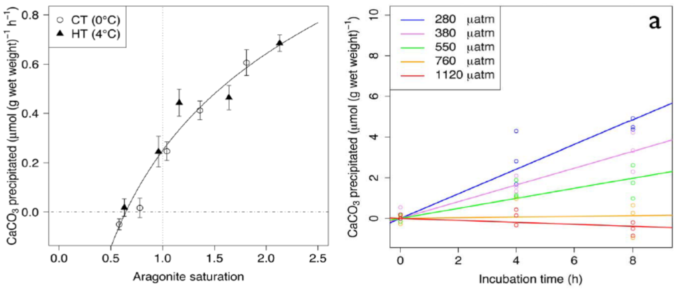
14C



45Ca

Radio isotopes

Calcium is taken up into the organisms skeletal components, the calcium uptake can be measured using radiolabelled elements (^{45}Ca, ^{14}C and ^{3}H) to estimate **net calcification**
Level: Organisms
Timescale: Minutes to hours
Pros: Extremely sensitive, Short-term incubations
Cons: Destructive, Non-biological adsorption, Use of radioisotopes restricted

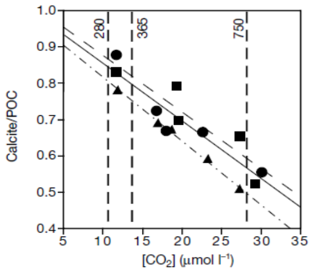


Comeau et al. 2010

Changes in particulate inorganic carbon (PIC)

Changes in the content of the particulate carbon content of an organism reflect its accumulation or loss of carbon and provide an estimate of **net calcification**.
Total particulate carbon (TPC) and particulate organic carbon (POC) are measured (CHN analyzer, mass spectrophotometry)**. PIC = TPC - POC.**
Level: Organisms
Timescale: Hours to days
Pros: Adequate with cultures and field samples (?)
Cons: Instrumentation, Not amenable to automation

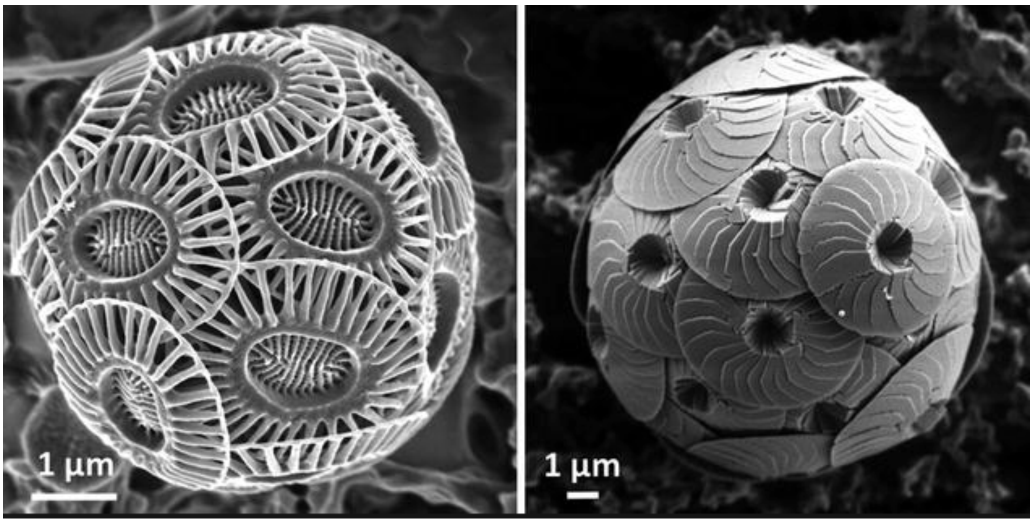
Growth rate
PIC concentration



Riebesell et al. 2000

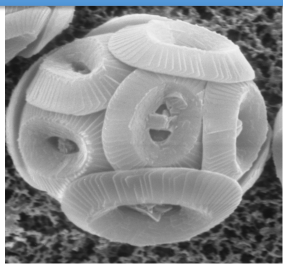
- Main planktonic calcifiers

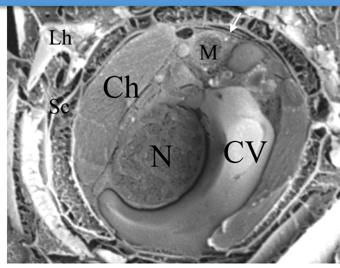
Coccolithophores

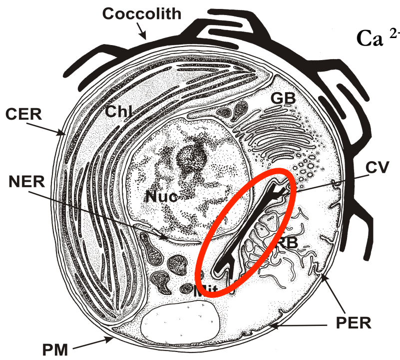


Coccolithophore calcification

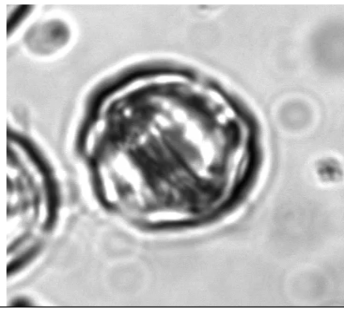
Calcification occurs in an intracellular compartment (coccolith vesicle)







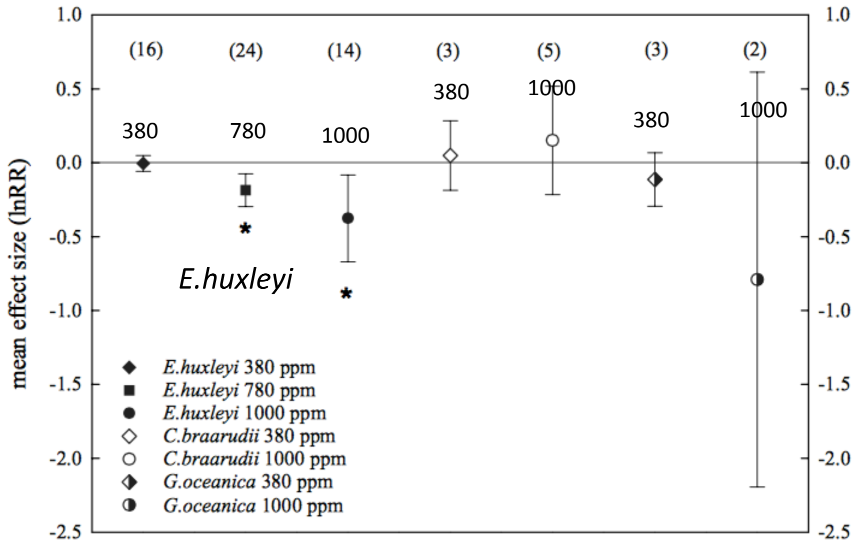
$$Ca^{2+} + 2HCO^{3-} \rightarrow CaCO_3 + CO_2 + H_2O$$



Brownlee and Taylor, 2004

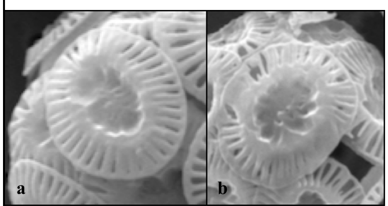
Coccolithophore culture experiments

Responses of coccolithophores to ocean acidification: a meta-analysis (from culture exp.)

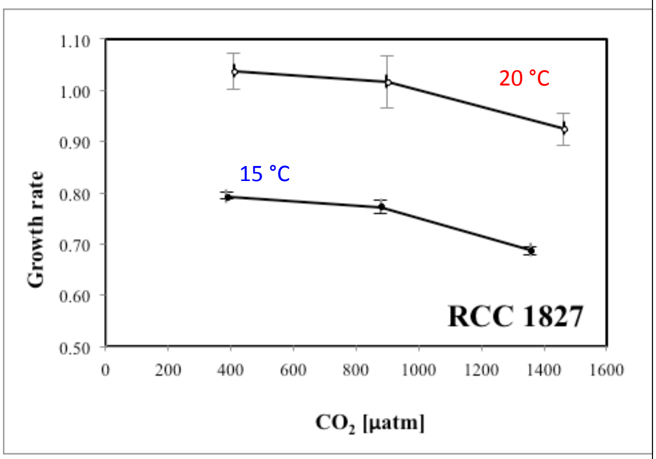


Meyer and Riebesell, 2015 BG

Ocean warming modulates the effects of acidification on *Emiliania huxleyi* calcification and sinking

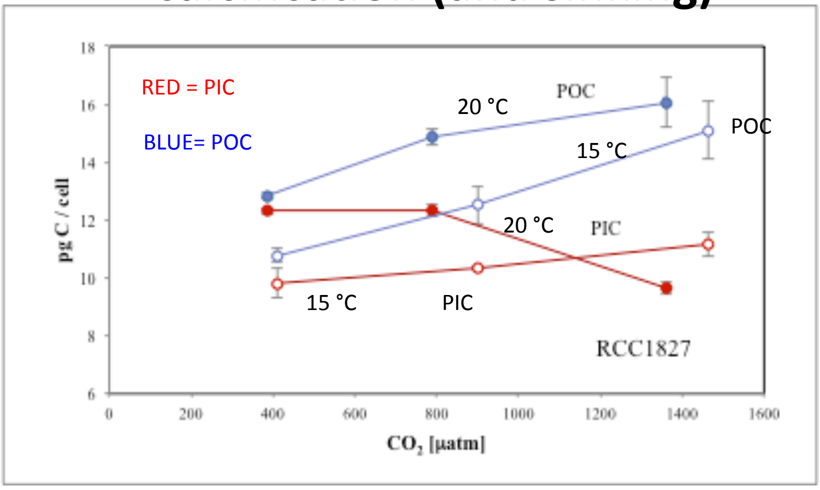


open circles (20 ºC)
closed circles (15 ºC)



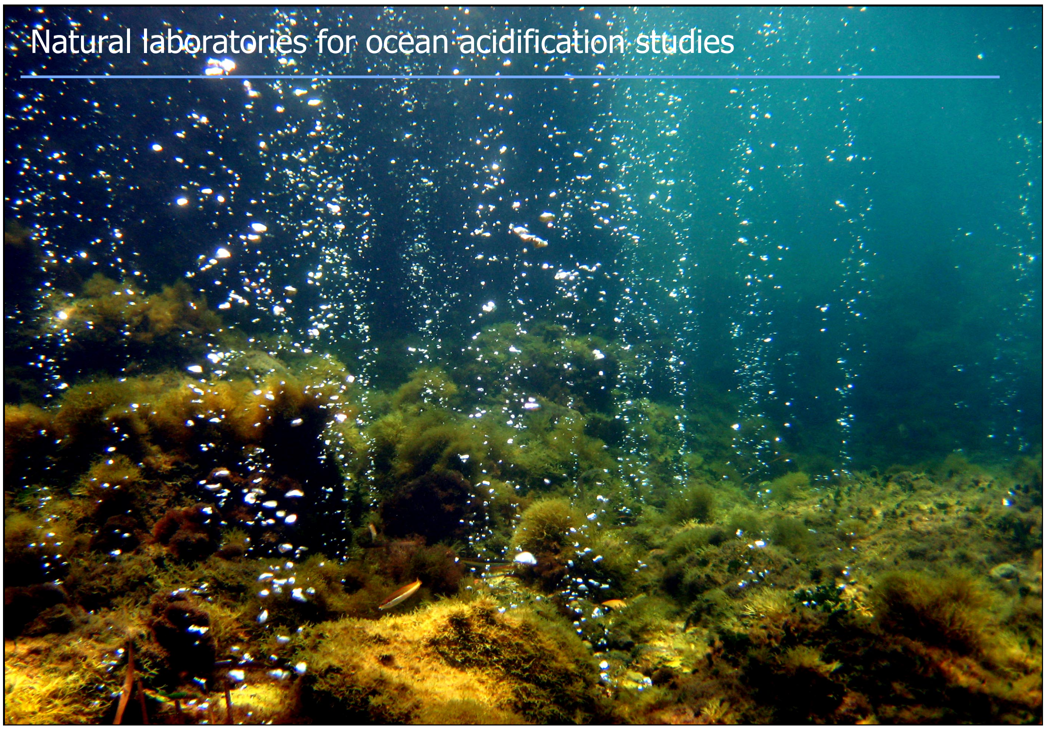
Milner, Langer, Ziveri, in press L&O

Ocean warming modulates the effects of acidification on *Emiliania huxleyi* calcification (and sinking)

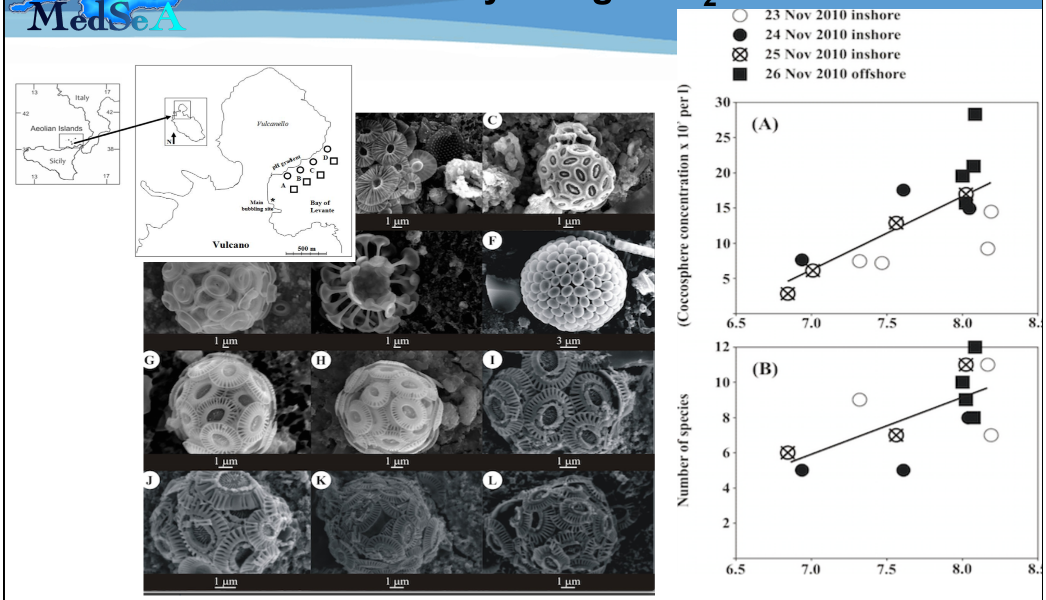


From lab experiments to field experiments: mesocosm approach

Natural laboratories for ocean acidification studies

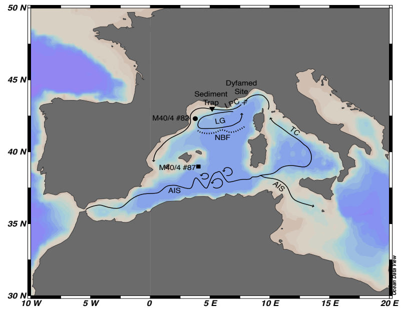


Biodiversity in high CO_2 conditions

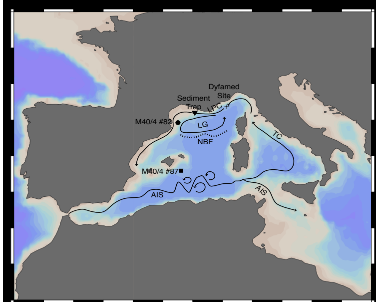


Decline in coccolithophore diversity and impact on coccolith morphogenesis along a natural CO_2 gradient

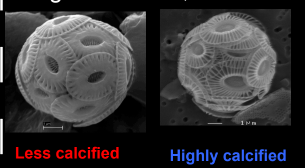
Ziveri et al., 2014

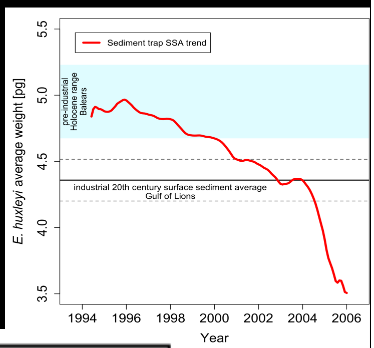


Ehux in Gulf of Lyon time-series 1994-2006

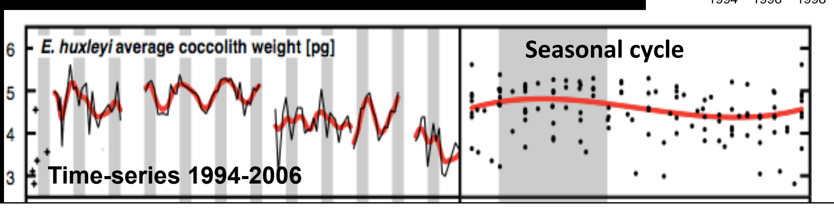


Meier K. J. S., Beaufort L., Heussner S. and Ziveri P.
The role of ocean acidification in *Emiliania huxleyi* coccolith thinning in the Mediterranean Sea.
Biogeosciences, 2014





The role of OA
in *E. huxleyi* coccolith thinning

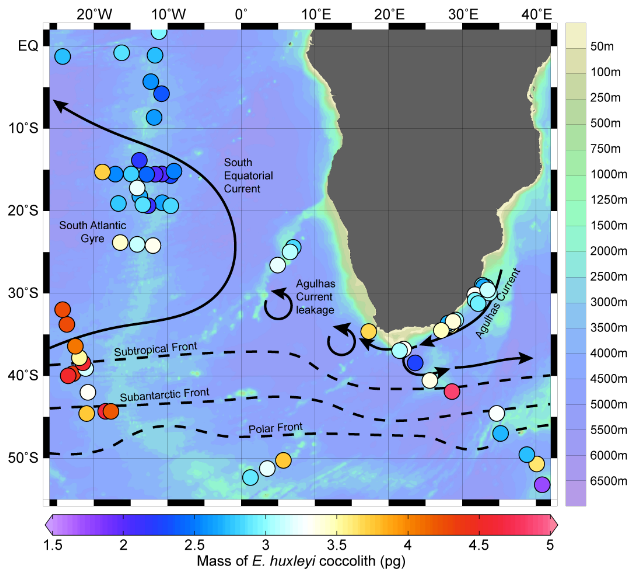


Environmental controls on the Emiliania huxleyi calcite mass

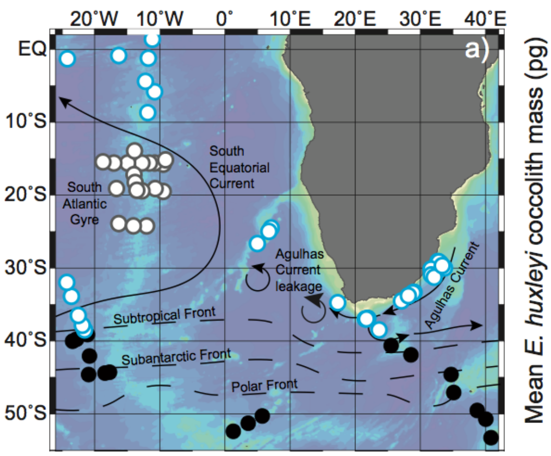
M. T. Horigome, P. Ziveri, M. Grelaud, K.-H. Baumann, G. Marino, and P. G. Mortyn, Biogeosciences, 2015

Surface sediments and the averaged mass of *E. huxleyi.*

Method:
Automated System of Coccolith Recognition (SYRACO)



Environmental controls on the Emiliania huxleyi calcite mass



Cluster analysis provided 3 clusters:

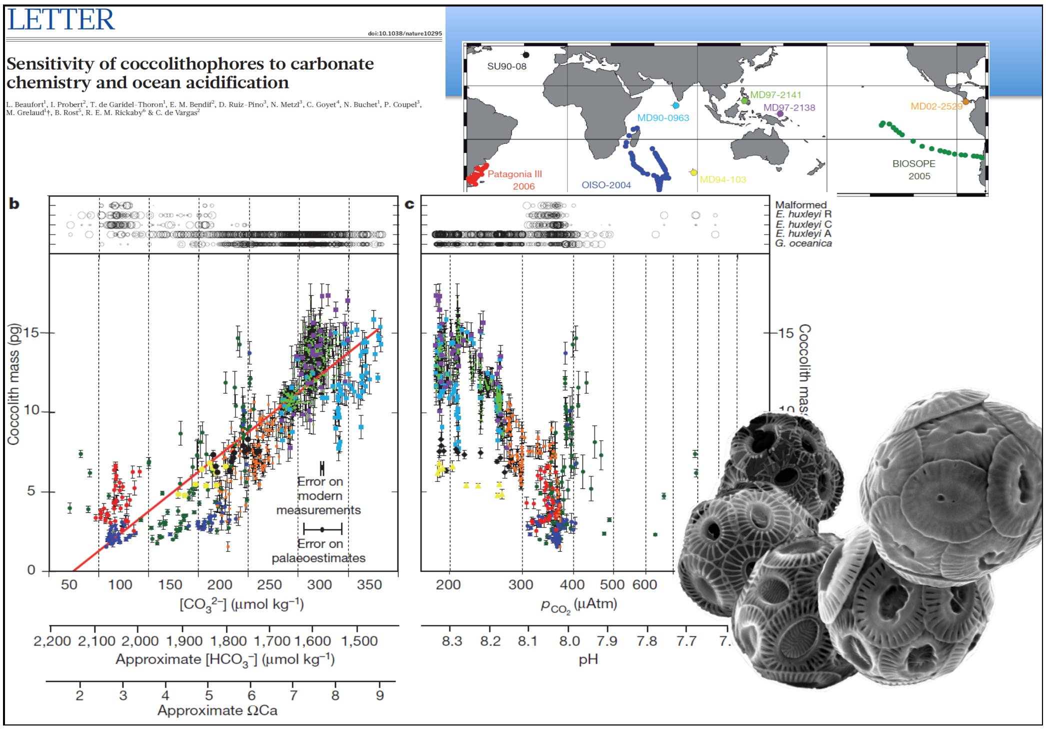
#1: The Aghullas Current, between the South Atlantig gyre and the Subtropical front, north to the South Atlantic gyre (blue open circles)

#2: The South Atlantic gyre (grey open circles)

#3: Below the Subtropical front

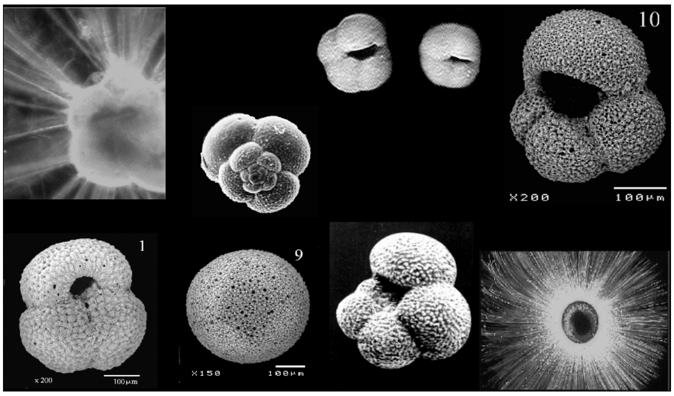
Relation between the mass of *E. huxleyi* and the environmental parameters within the 3 clusters (black circles).

	Temperature	Salinity	Chl *a*	Nitrate	Phosphate	pH	pCO_2	$[CO_3^{2-}]$
Cluster #1	**−0.537**	−0.225	−0.155	−0.116	0.022	**0.621**	**−0.605**	0.018
Cluster #2	0.252	0.197	**−0.652**	**−0.660**	**−0.704**	0.383	−0.391	0.371
Cluster #3	**0.609**	**0.562**	**0.557**	**−0.632**	**−0.620**	−0.163	0.090	**0.554**
Entire data set	**−0.305**	**−0.359**	**0.406**	0.088	0.134	**0.356**	**−0.372**	**−0.268**

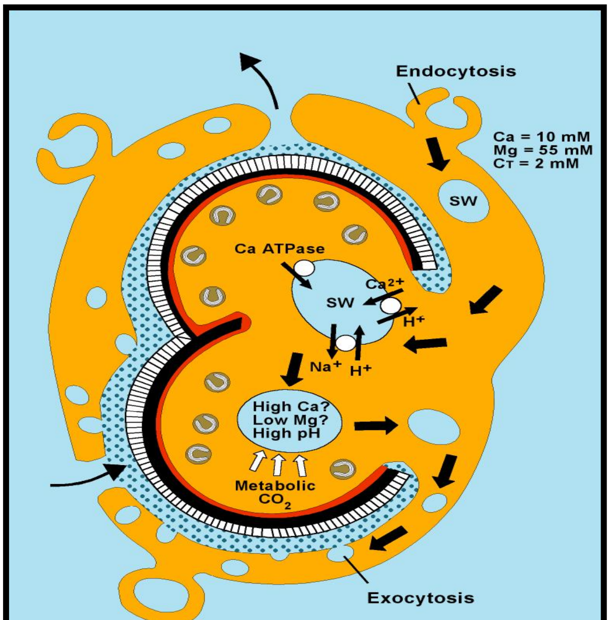


Foraminifera

What are planktonic foraminifera?



Planktonic foraminifera are calcareous zooplankton that inhabit the upper few hundred meters of the surface ocean, for a lifetime of several weeks to a month or so. We can see the different chambers, from the smaller inner ones to the larger outer ones, reflecting growth changes from juvenile to adult stages of an individual life cycle. These organisms live inside of their protective carbonate "exoskeleton". The soft tissue of the animal is called protoplasm and the animal feeds on phytoplankton and algal particles in the surrounding waters. The animal extrudes its reticulopodia (rhyzopodia, sp.?) outside of the shell, using the spines for structural support. The rhyzopodia are sticky and the particles attach to their adhesive surfaces. The animal senses the capture of the food particles, and then brings the meal back home for digestion.



(from Erez, 2003)

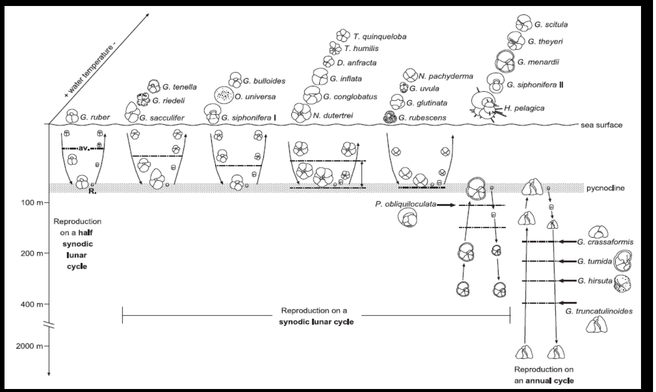
Ions are transported by vacuolization of seawater

BUT recent models include a transmembrane transport component similar to coccos as well >> Nehrke et al. 2013

Erez 2003

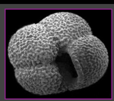
Planktonic foraminifera

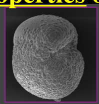
- Marine micro-zooplankton that inhabits the upper several 100s meters of the water column;
- Different species dwell at different depths of the water column;
- Shells are made of **calcium carbonate** ($CaCO_3$);



Schiebel and Hemleben, 2005

Planktonic foraminifera archive in their shells information about the physicochemical properties of the water mass in which they calcified


N. pachyderma (s.)

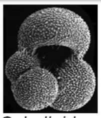

G. crassaformis (s.)

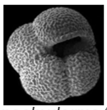

G. bulloides

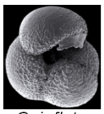

G. ruber (s.l.)

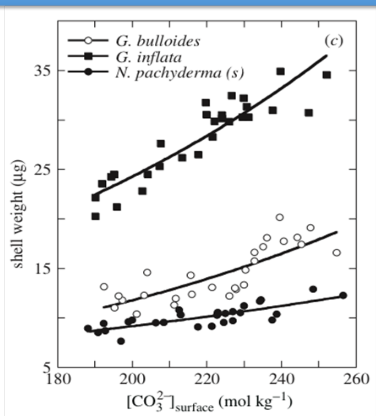

G. ruber (s.s.)

Response of planktic foraminifera to changes in the seawater carbonate parameters (Glacial-Interglacial)


G. bulloides


N. pachyderma (s)


G. inflata



Barker & Elderfield, 2002 – *Science*

The weight of several planktic foraminiferal species appears to decrease when the [CO_3^{2-}] of the seawater in which foraminifera calcify decreases.

nature geoscience

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Letter

Nature Geoscience **2**, 276 - 280 (2009)
Published online: 8 March 2009 | doi:10.1038/ngeo460

Subject Categories: Biogeochemistry | Oceanography

Reduced calcification in modern Southern Ocean planktonic foraminifera

Andrew D. Moy[1,2], William R. Howard[1], Stephen G. Bray[1] & Thomas W. Trull[1,3,4]

Globigerina bulloides **collected from sediment traps in the Southern Ocean with the weights of shells preserved in the underlying Holocene-aged sediments. We find that modern shell weights are 30–35% lower than those from the sediments, consistent with reduced calcification today induced by ocean acidification. We also find a link between higher atmospheric carbon dioxide and low shell weights in a 50,000-year-long record obtained from a Southern Ocean marine sediment core**

Pteropods

These corrosive conditions dissolve shells of sea butterflies (Thecosomata)

Movie: Brad Seibel, University of Rhode Island

Orr et al. (2005)

Fabry et al. (2008)

Comeau et al. (2009; 2011; 2012)

Lischka et al. (2011); Lischka & Riebesell (2012)

Bednarsek et al. (2012)

Sea butterfly shells ($CaCO_3$) exposed to corrosive conditions expected by 2100

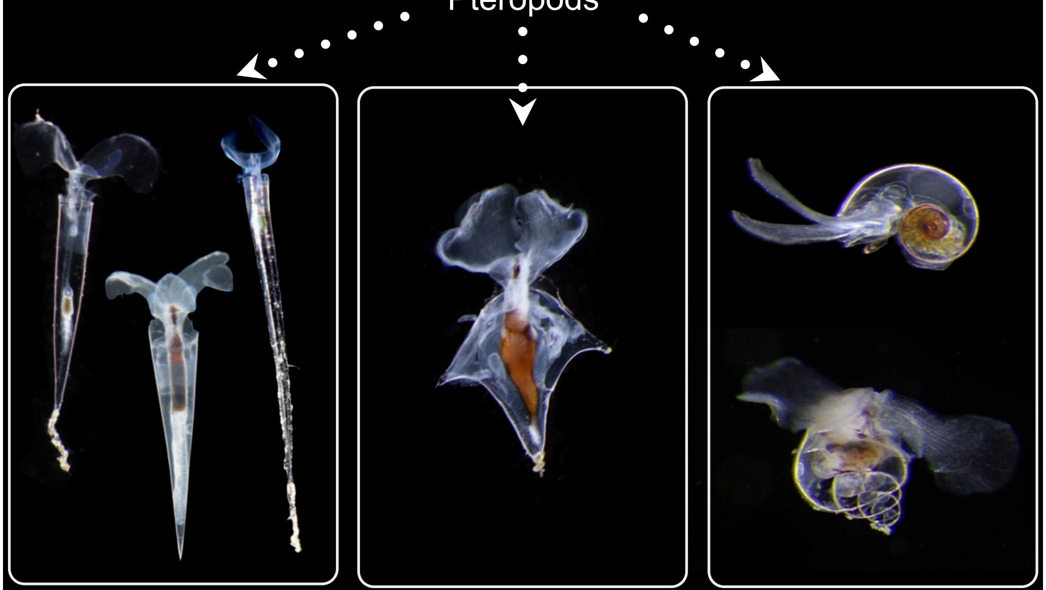
Day 1

Day 2

Day 16

Image: Victoria Fabry, California State University San Marcos

Pteropods

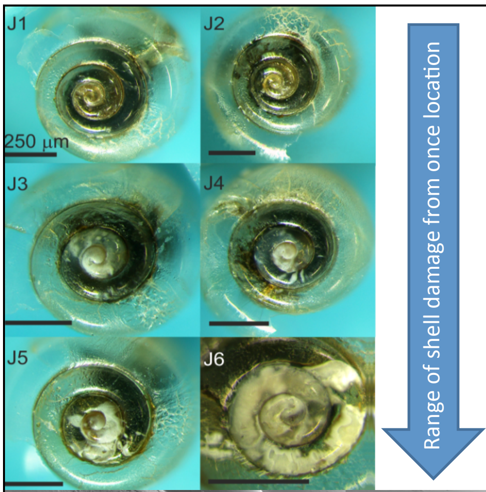


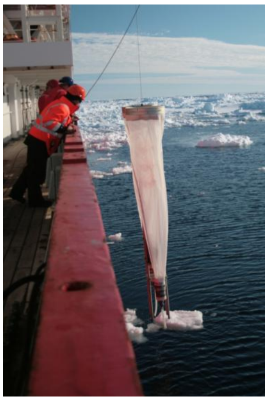
Creseidae

Cavolinidae

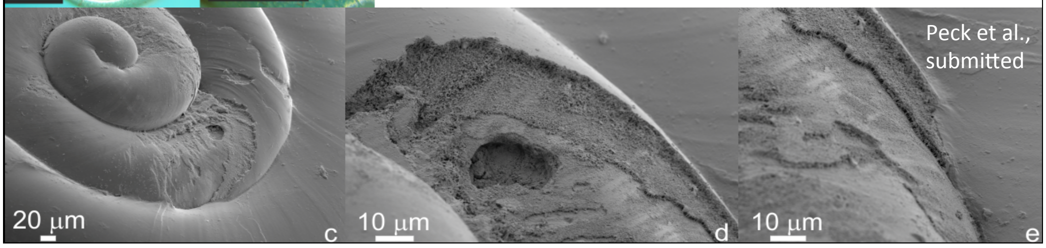
Limacinidae

Pteropods

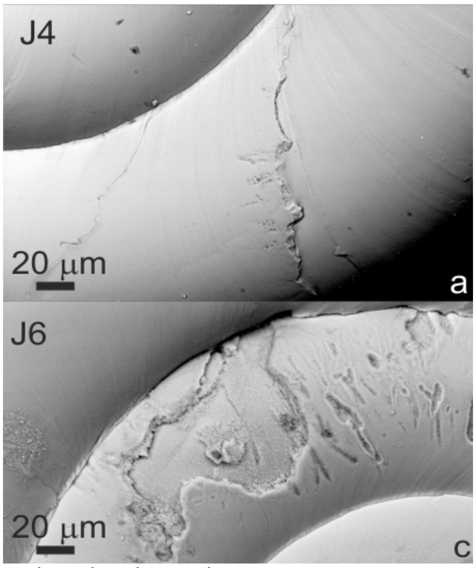




Extent of damage depends on amount of damage in the organic coating on the outside of the shell

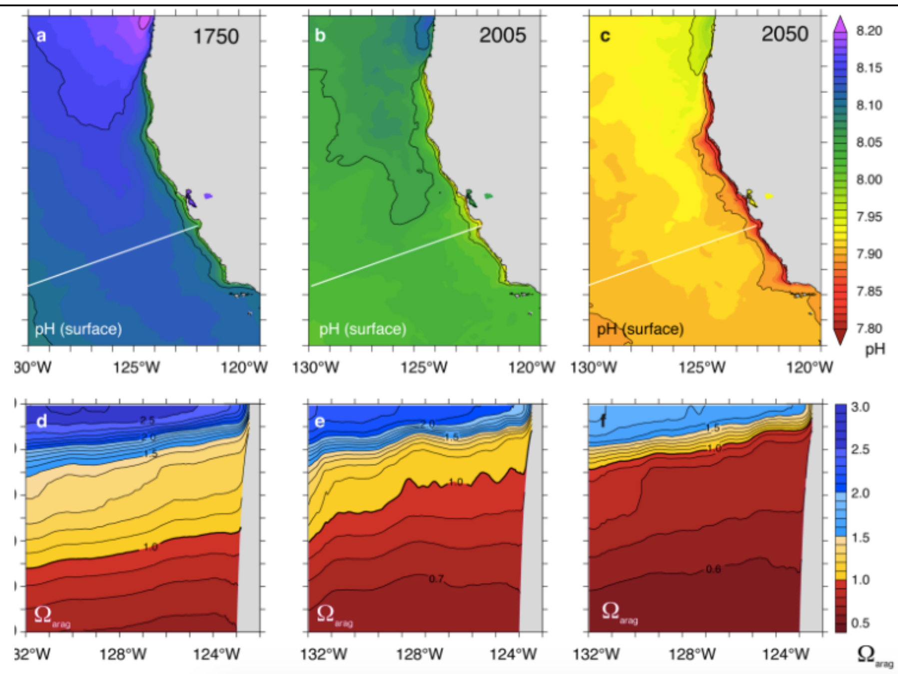


Predator damage to the shell is especially susceptible to dissolution



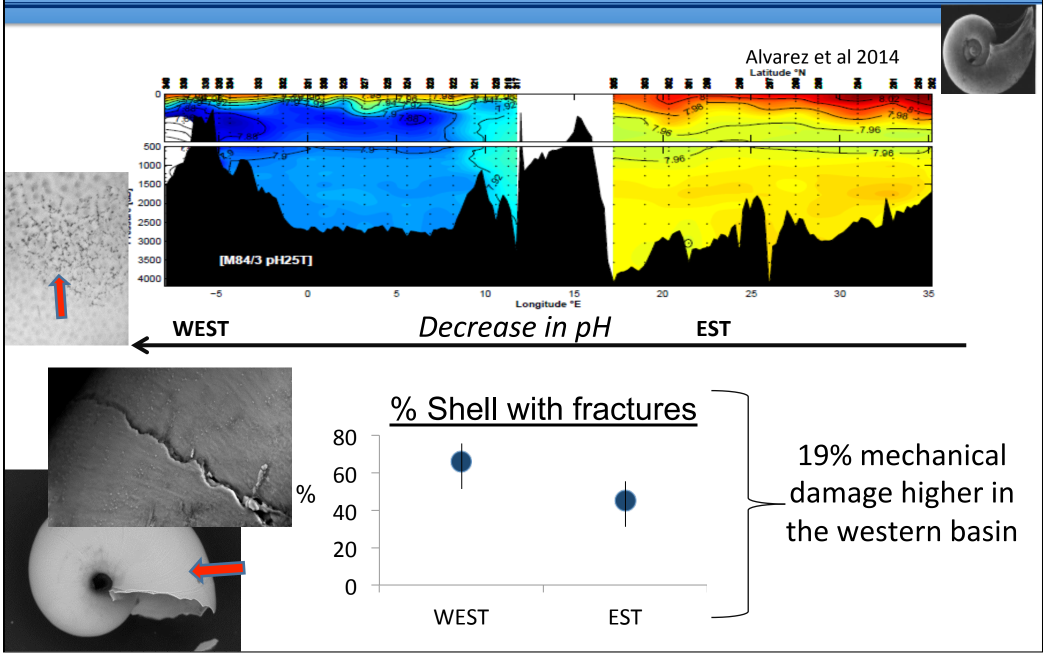
Peck et al., submitted

Bednarsek and Ohman, 2015, MEPS



Gruber et al., 2012 Science

Shell fitness vs. carbonate chemistry gradient



Summary

- Planktonic calcifiers: what do you want to study (clear scientific questions)
- Approach: Lab experiments, field experiments, field observations (time-series, oceanographic cruises)
- Lab experiments: reproduce environmental conditions and scenarios for your target region (if possible): clear scientific questions (hypothesis)
- Monitoring
- Field observations (associated to environmental parameters)

Take home message planktonic calcifying organisms

- Key component of the marine carbon cycle
- Base of the food web

- OA ➔ general reduced calcification ➔ Species specific response

- Pteropods as Ocean's Canary in the Coal Mine (?)

Calcification References

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N. Keul, G. Langer, L. J. de Nooijer, and J. Bijma (2013) Effect of ocean acidification on the benthic foraminifera Ammonia sp. is caused by a decrease in carbonate ion concentration. Biogeosciences, 10, 6185-6198

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