Geochemical Proxies

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What can Deep Corals Tell Us?

Ocean Archives

- Cold water coral skeletons trap trace elements and isotopes from the ambient seawater as they form.
- The composition of the skeleton reflects chemical/ physical/biological processes occurring at the time.
- Skeletons therefore represent an archive of ocean conditions.

What can Deep Corals Tell Us?

Ocean Archives

- Cold water corals grow in a wide range of environments, including the deep oceans.
- Can provide information on short timescale processes occurring in the oceans (years to centuries)
- Sediment cores do not often provide reliable information on these timescales.

Two Different Types

Scleractinian Corals

- e.g. Lophelia
- Short Lived.
- Plentiful (reef builder)
- Aragonite Skeleton

- Short time-series (10s of years at most)
- Can recover fragments in long sediment cores.
- Samples in cores may be millions of years old.

Glacial Timescale Climate Reconstruction

Gorgonian Corals

- e.g. Bamboo Corals
- Long Lived.
- Rare (single colonies)
- Calcite/Organic Skeleton

- Long time-series (100s – 1000s of years)
- May find sub-fossil individuals.
- Old samples possible, but very rare.

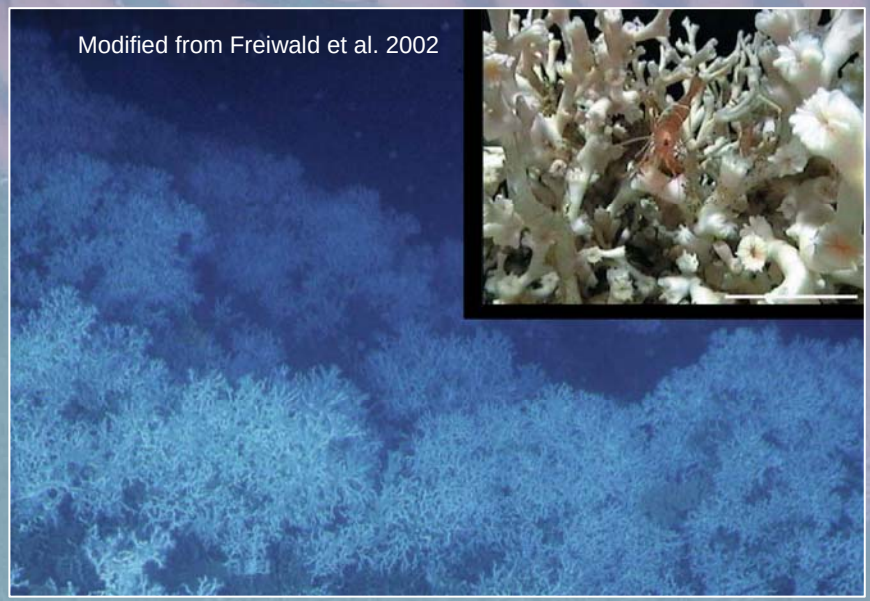
Anthropogenic Timescale Climate Reconstruction

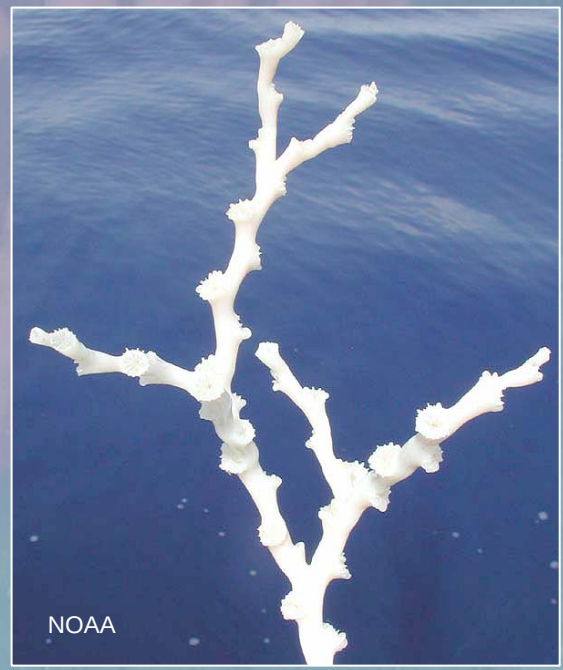
Very different strategies required for paleoceanographic reconstruction

Scleractinian Corals

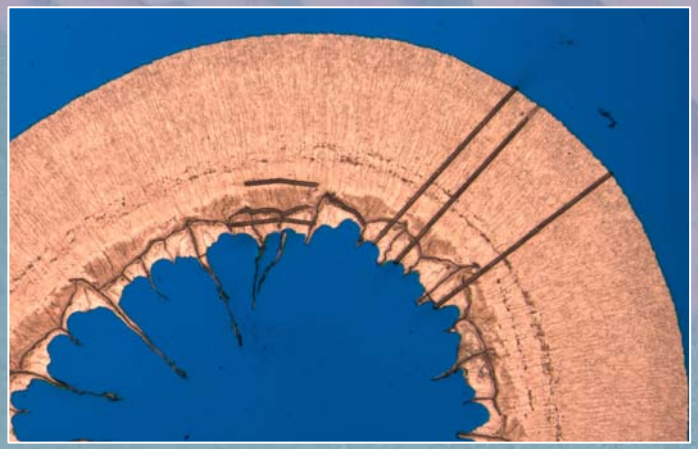
Growth Form

- Thickets of intertwined branches.
- Large polyps – each grows over several years.
- Polyps live 5-10 years before being ‘overgrown’.
- Skeleton continues to thicken during this time.

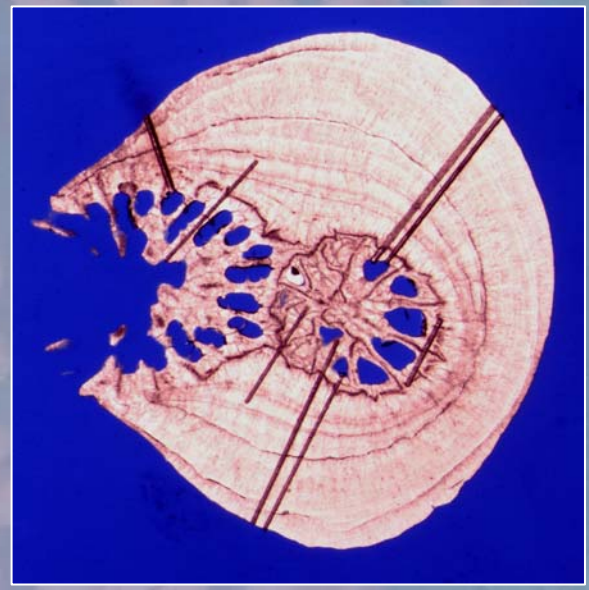


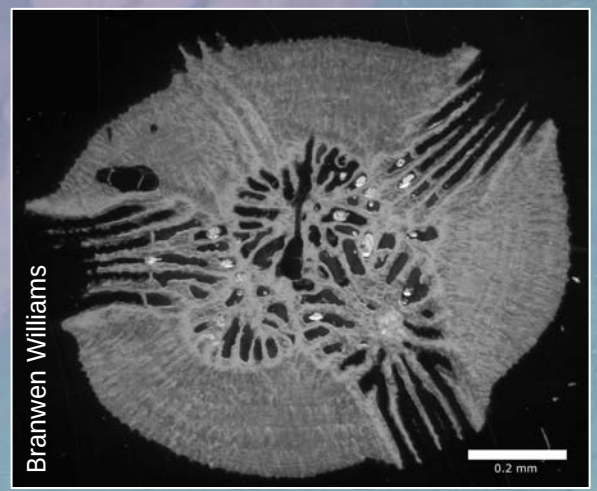


Lophelia

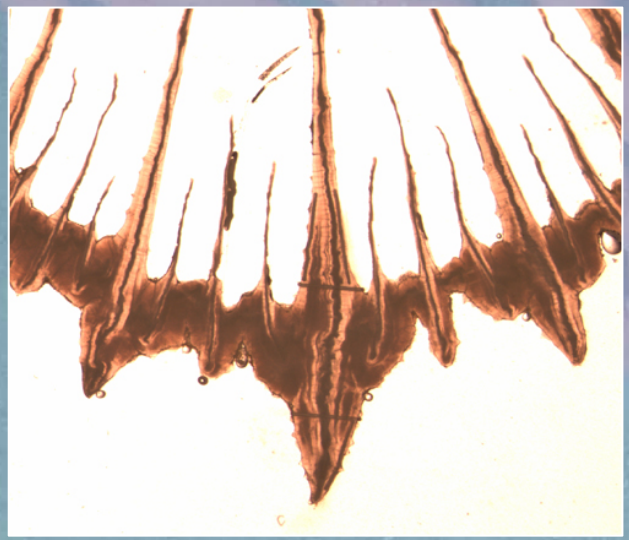


Oculina



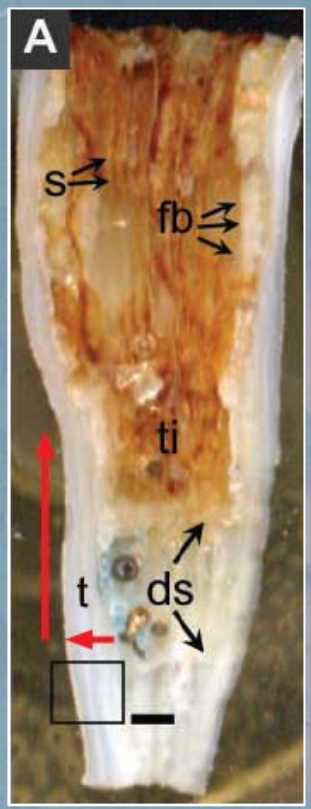


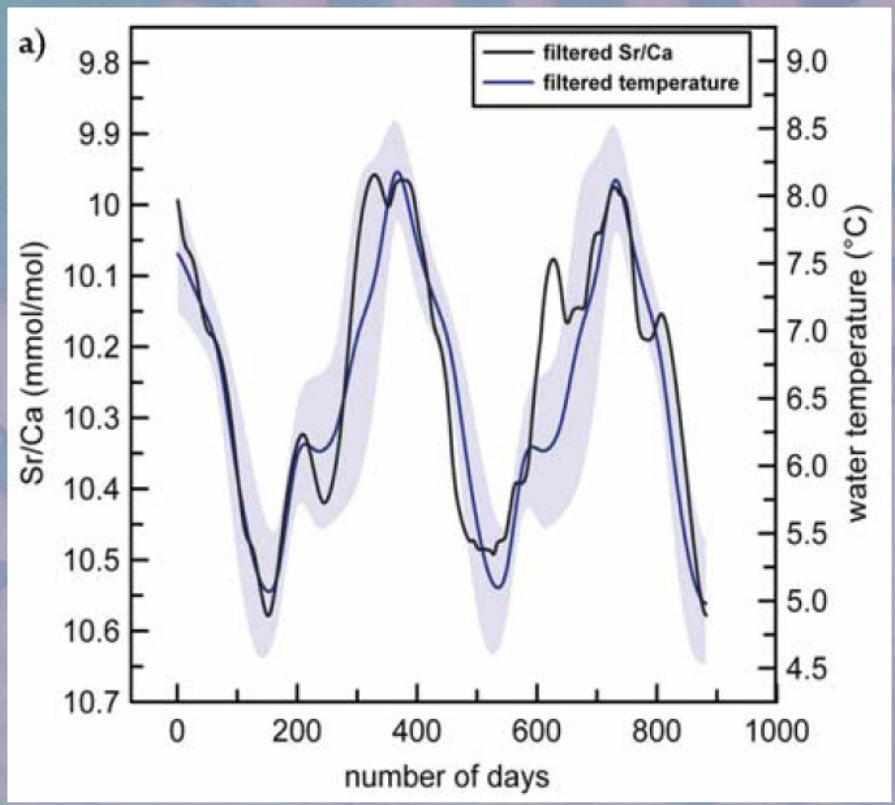
Desmophyllum



- Solitary Coral
- Longer Lived than Lophelia

Interannual Variations



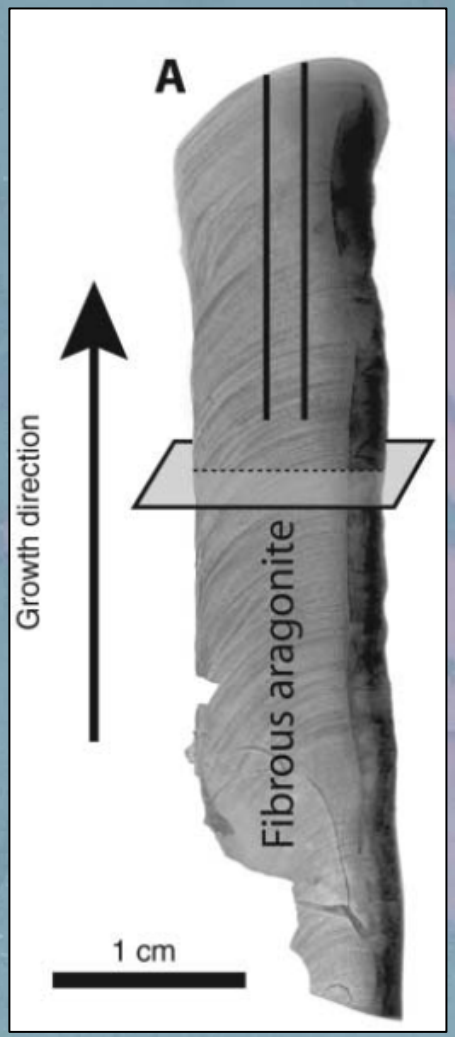


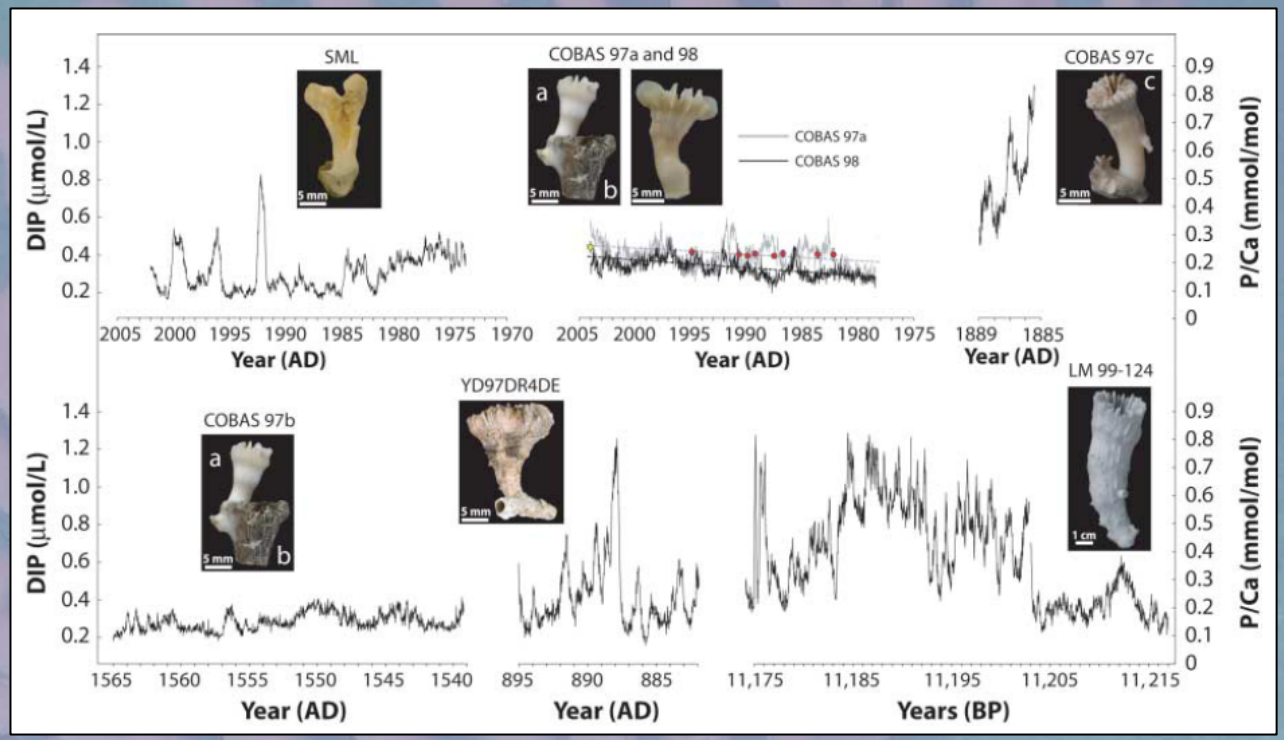
From Cohen et al. 2006

Temperature mediated trace element inclusion

- Measured along thecal wall.
- Inorganic and biologica response.
- Potential for temperature reconstruction?

Interannual Variations





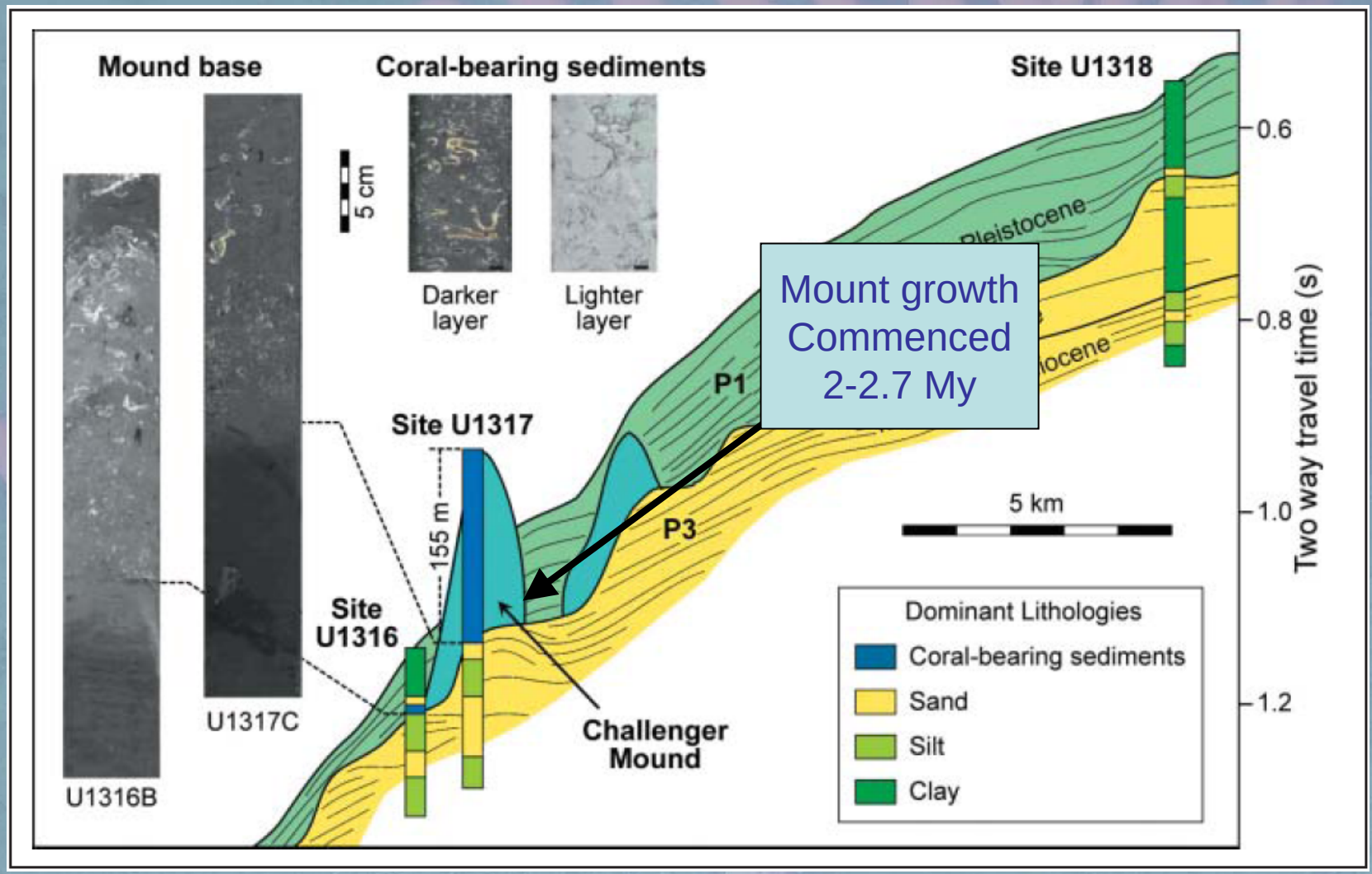
From Montagna et al. 2006

Phosphorous as a nutrient proxy.

- Desmophyllum: longer lived than Lophelia.
- Measured along a Septum.

Drilling Carbonate Mounds

IODP 307



Williams (and many many others) EOS 2006

The ‘Holy Grail’…

Interannual variability over 1,000,000 years!?!

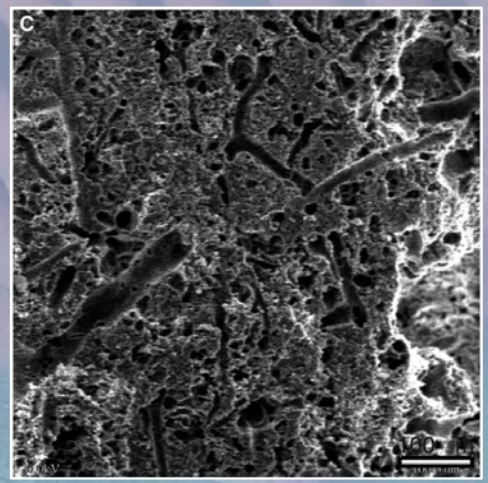
- Unfortunately...

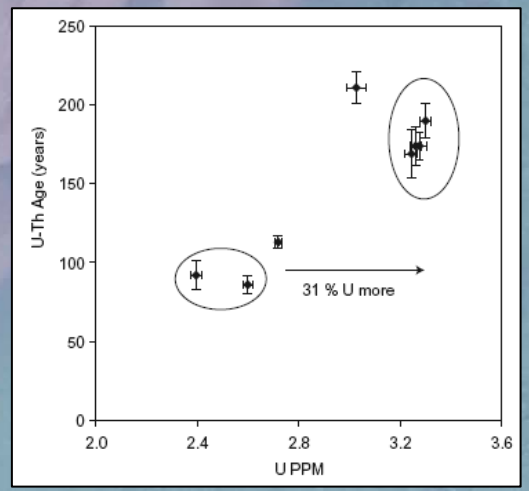
(there’s always an ‘unfortunately’)

Complications

Chemical/Physical changes to samples

- Can occur rapidly.
- Diagenesis / ‘Open System’
- Bioerosion
- Old fragments may be no good for geochemistry.





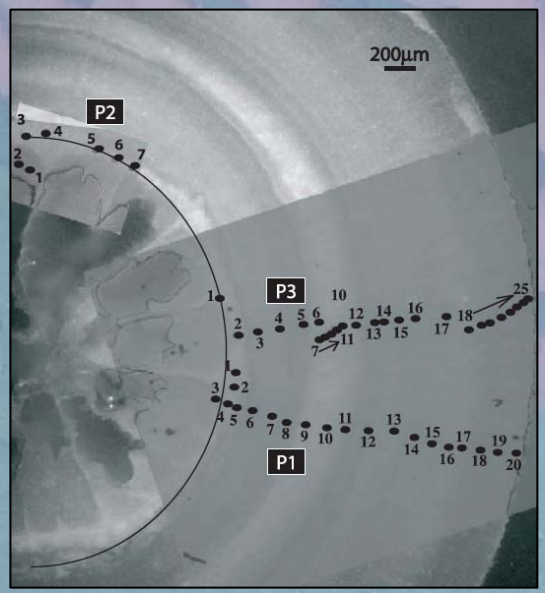
Pons-Branchu et al. 2005

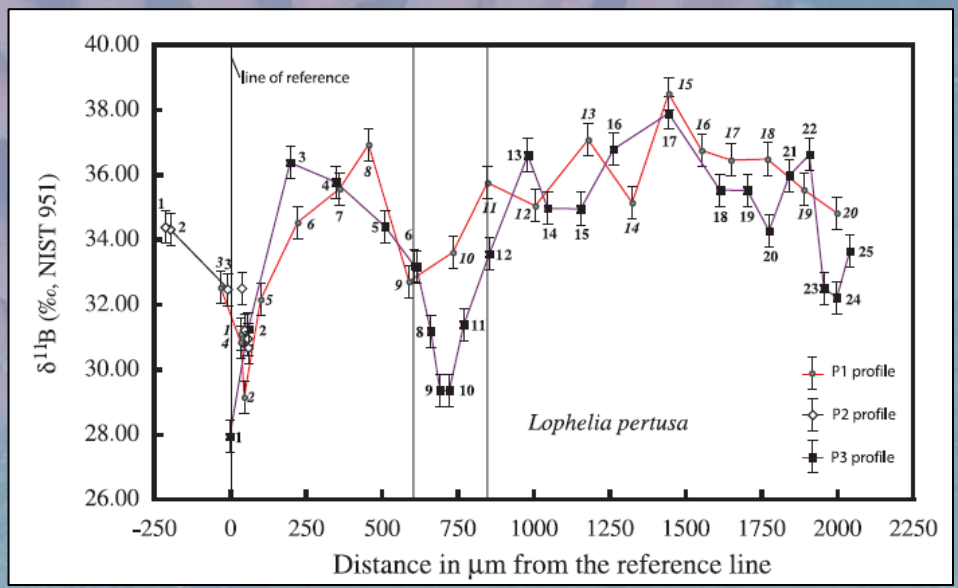
Complications

Chemical Tracers Affected by ‘Vital Effects’

- Biology influences uptake of elements/isotopes.
- Internal structures have characteristic chemistry
- Known to affect: $\delta^{11}B$, $\delta^{18}O$, $\delta^{13}C$, Mg, U + others.
- Could it also affect Sr and P?

Blamart et al. 2007

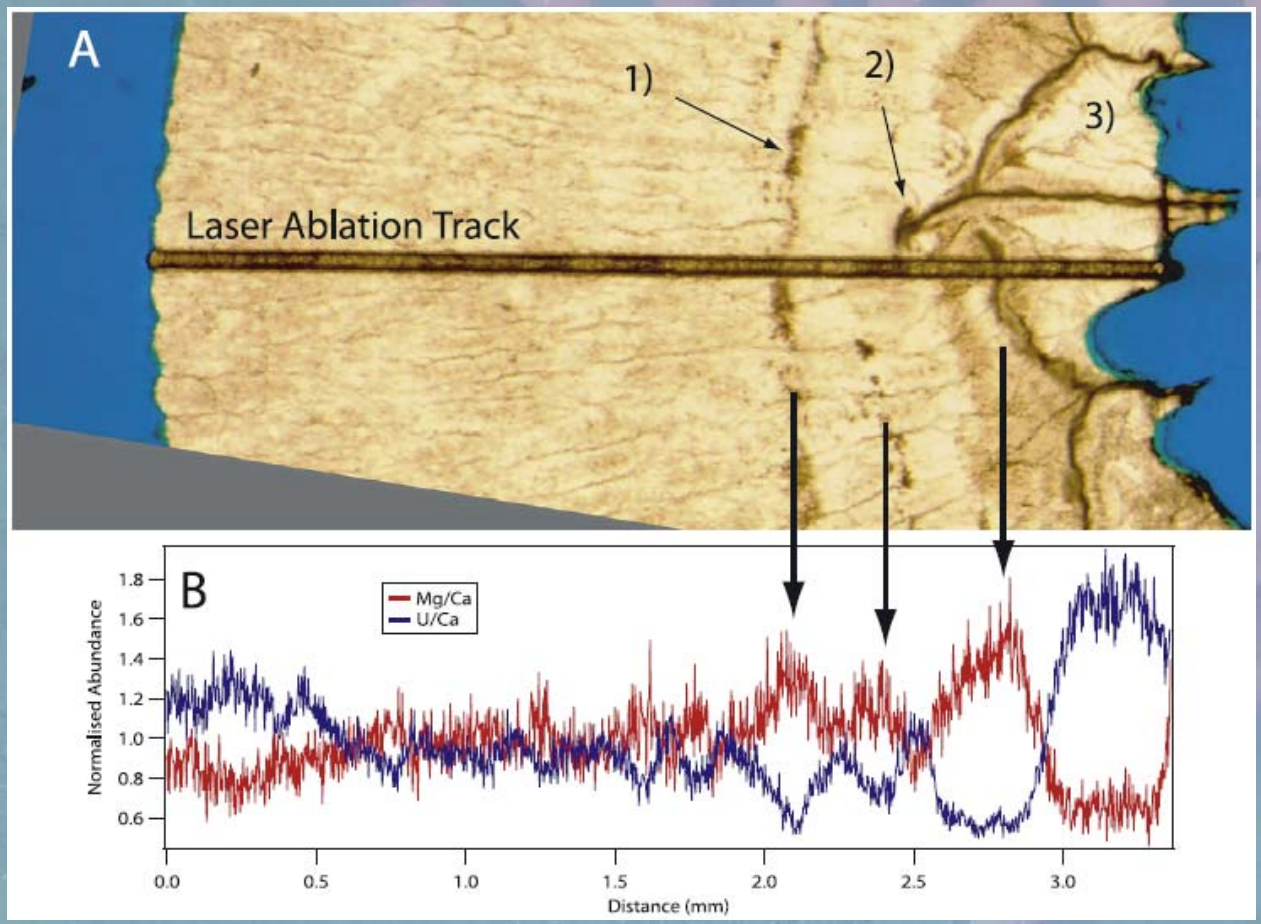




Complications

Vital Effects

Sinclair et al. 2006



- Elements controlled by internal structure.
- Makes time-series difficult: Can't be sure whether a feature is an environmental fluctuation or an EMZ.
- Target very inside region?
- Might be able to get a time series by cutting polyp longitudinally (eg. Cohen et al. 2006, but at most get *3 years.*
- Possibly get only *1 data point per coral fragment.*

Is There Hope?

Deep Corals Might Still Record ‘Average State’

- ‘Vital Effects’ might complicate time-series.
- But maybe the whole coral (or selected regions) can give an ‘average’ of the environmental state.
  - Assumption: on average ‘vital’ effects are constant through time and/or are consistent between individuals.
  - People using tropical Scleractinians make these assumptions, and there are clearly cases where it works well.

Is There Hope?

Some Isotope Systems Might be ‘Immune’ from Vital Effects.

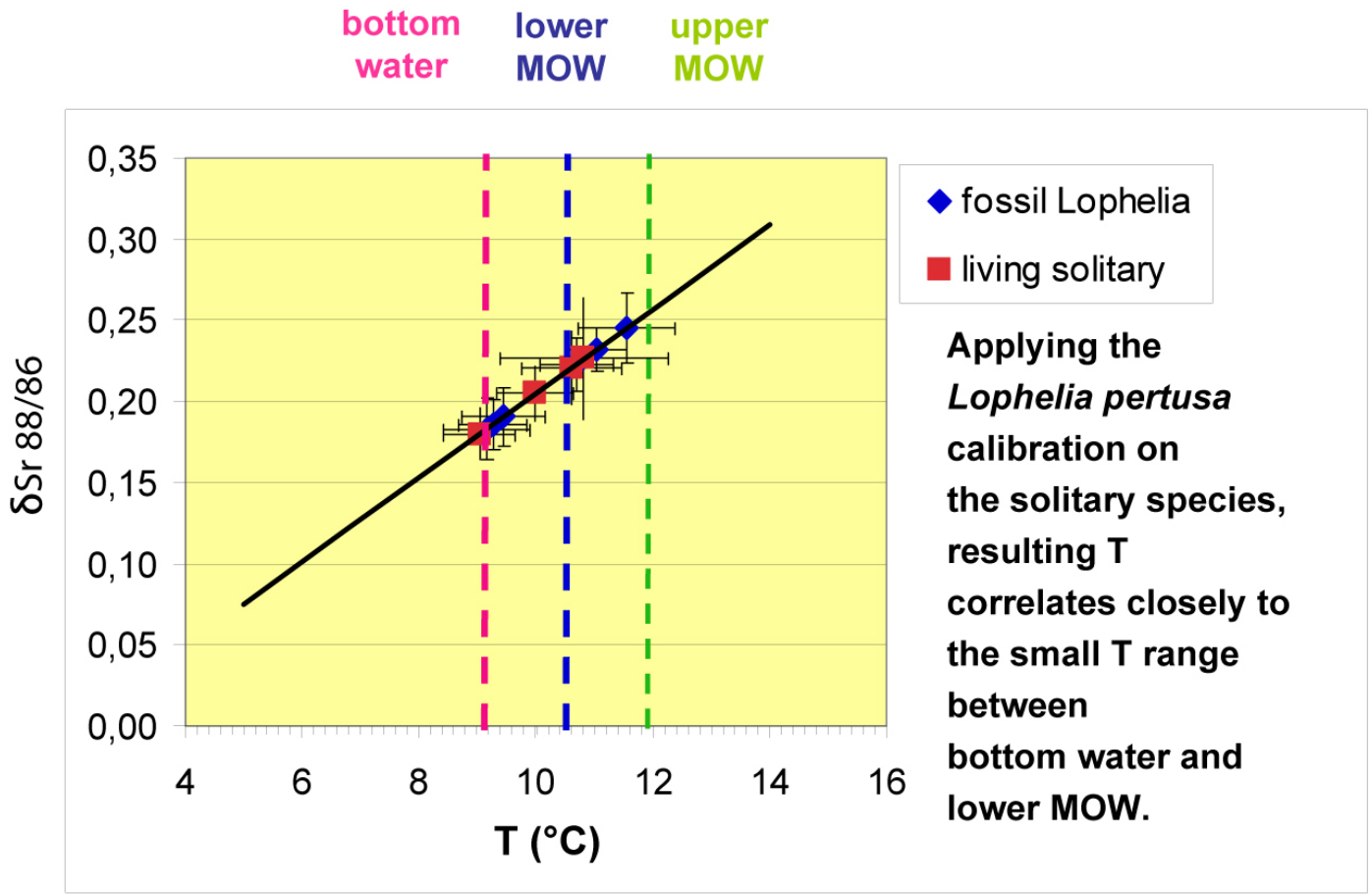
- Isotopes of heavy elements:
  - Not discriminated biologically
  - Not discriminated chemically
- May have variable environmental distributions (often one isotope is radiogenic)
- Examples: Pb isotopes, Nd isotopes (more from Norbert Frank)
- Often very low concentrations: need a lot of sample. Limits resolution of time series.

Implications for Sampling

One Data Point per Coral Fragment

- Need multiple corals from multiple times/locations to build up an environmental story.
  - e.g. Multiple fragments of different ages from the same location (such as a core down through a mound).
  - e.g. Multiple fragments of the same age from different locations (such as a geographical transect).
- Need for calibration studies: corals from environments with known environmental gradients - e.g. temperature/depth/nutrient transect.
- Need to set up site-monitoring as well as co-ordinate coral sampling?
- Need to plan sampling around specific environmental hypotheses.

Sr-isotopes as new tracer of temperature



From Adkins talk (North American TRACES meeting)

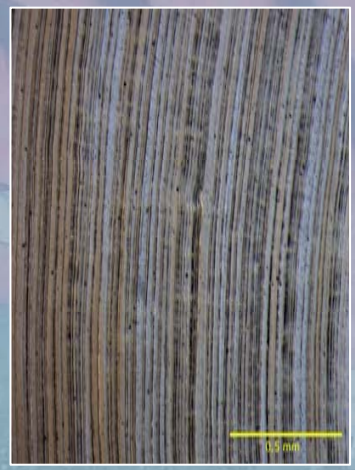
Liebetrau et al., Goldschmidt-2007, A-579

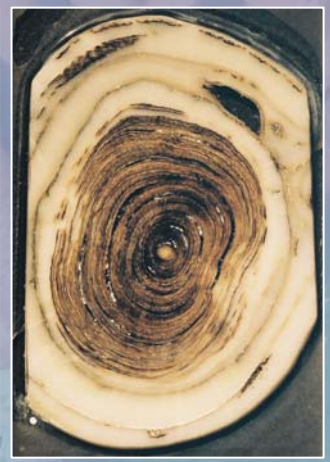
IFM-GEOMAR

Gorgonian Corals

Growth Form

- Single tree-like coral.
- Skeletons grow and thicken radially with periodic banding.
- Corals can be 100s to 1000s of years old!
- Potential for continuous record throughout life of coral.
- Organic and calcitic skeletons.

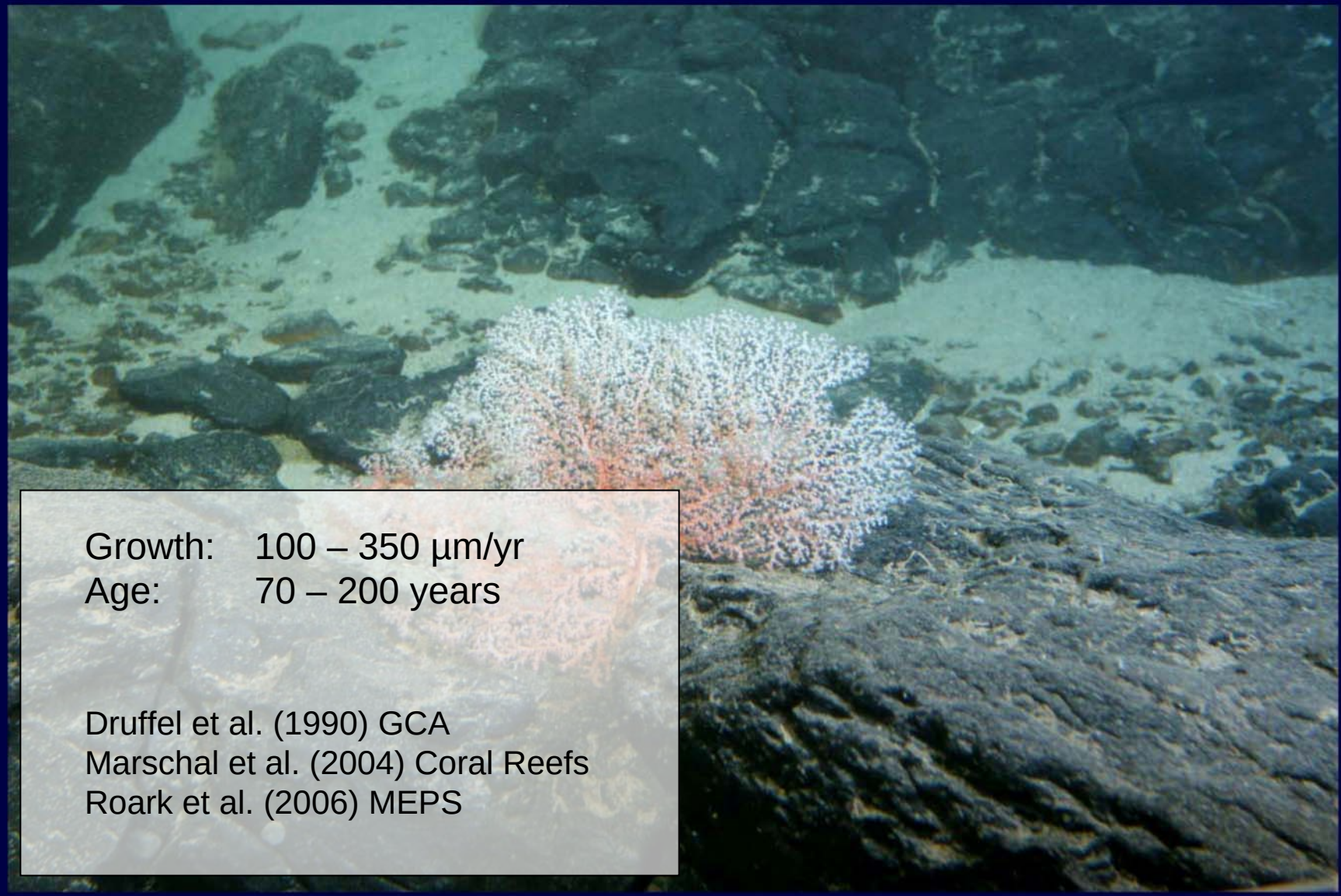




Gorgonians

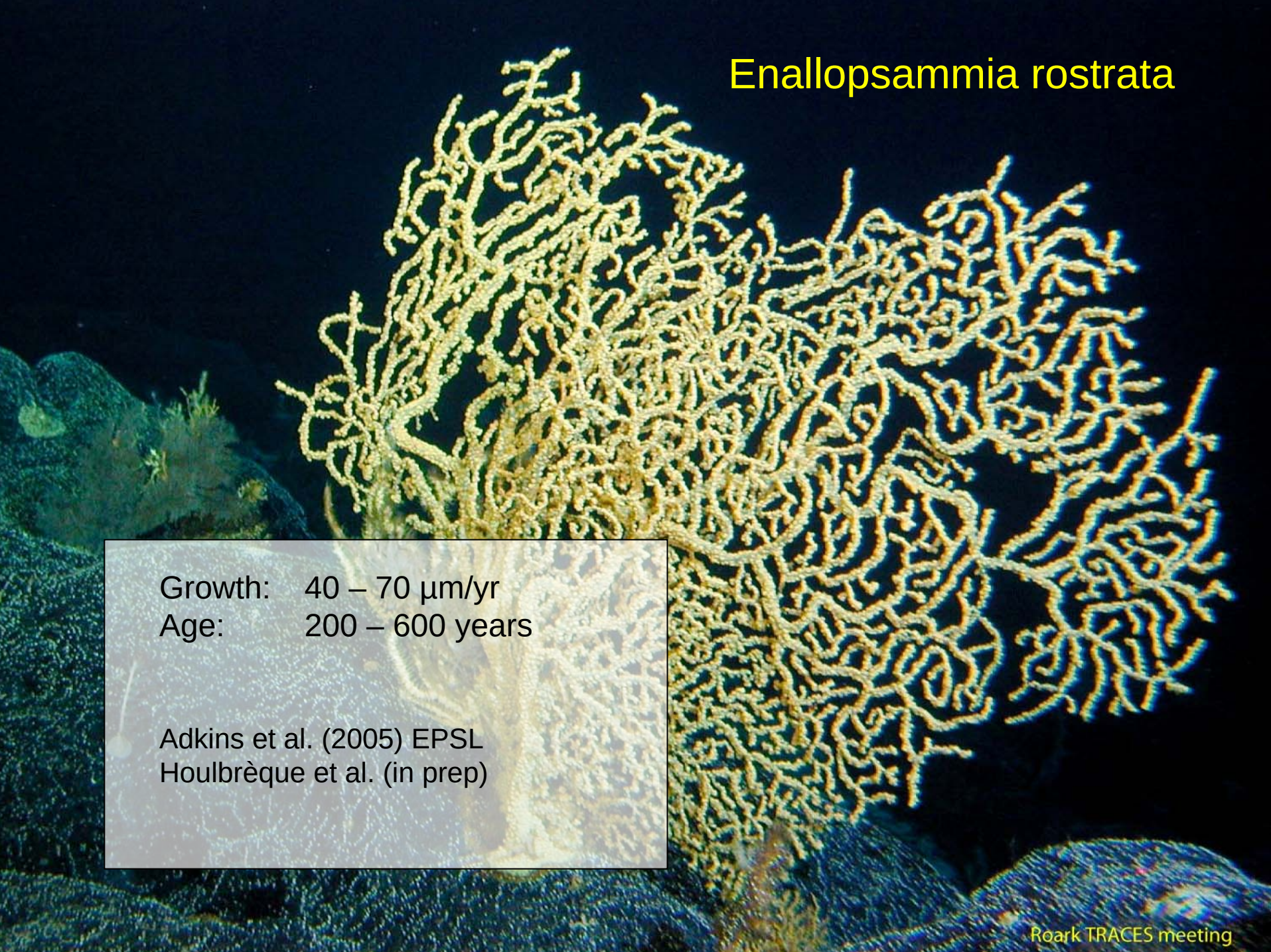
Here I shamelessly pinch slides from Brendan Roark's excellent presentation to the American TRACES workshop…

Corallium sp.

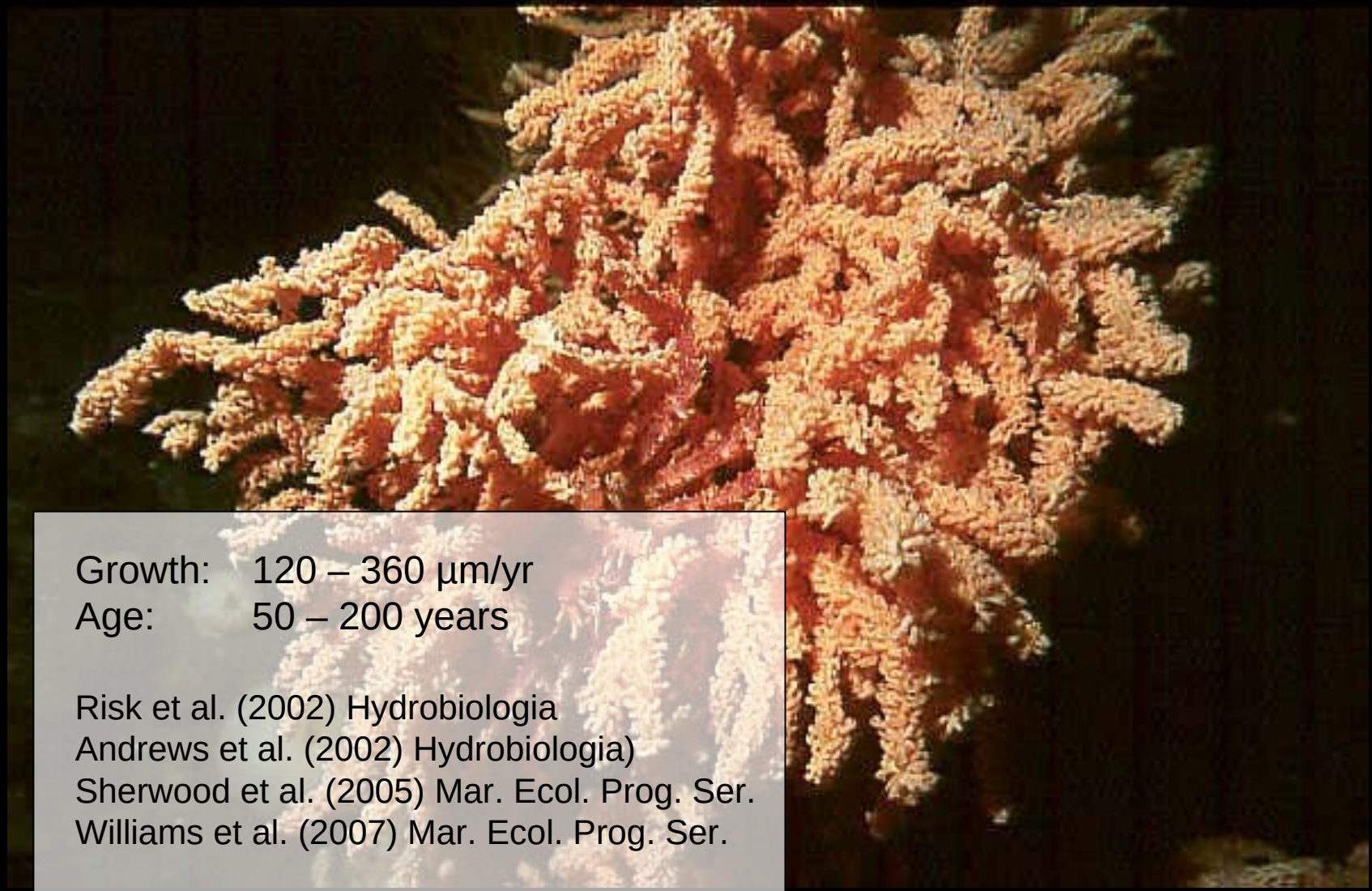


Growth: 100 – 350 µm/yr
Age: 70 – 200 years

Druffel et al. (1990) GCA
Marschal et al. (2004) Coral Reefs
Roark et al. (2006) MEPS


Enallopsammia rostrata
Growth: 40 – 70 µm/yr
Age: 200 – 600 years
Adkins et al. (2005) EPSL
Houlbrèque et al. (in prep)
Roark TRACES meeting

Primnoa resedaeformis

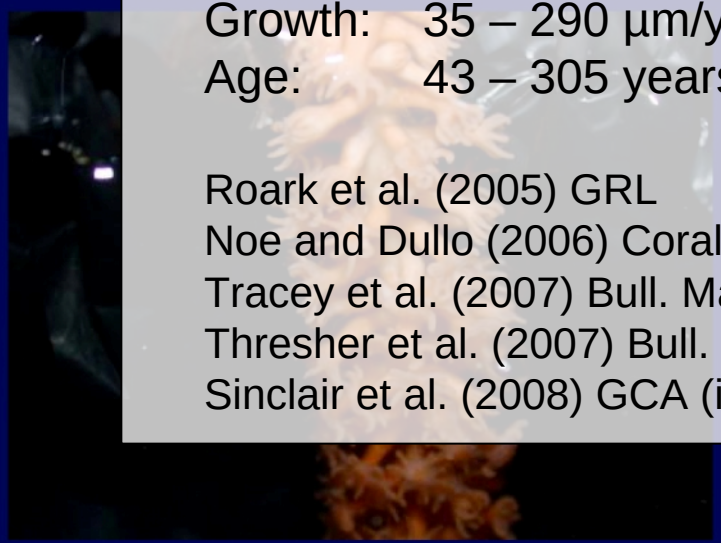


Growth: 120 – 360 µm/yr
Age: 50 – 200 years

Risk et al. (2002) Hydrobiologia
Andrews et al. (2002) Hydrobiologia)
Sherwood et al. (2005) Mar. Ecol. Prog. Ser.
Williams et al. (2007) Mar. Ecol. Prog. Ser.

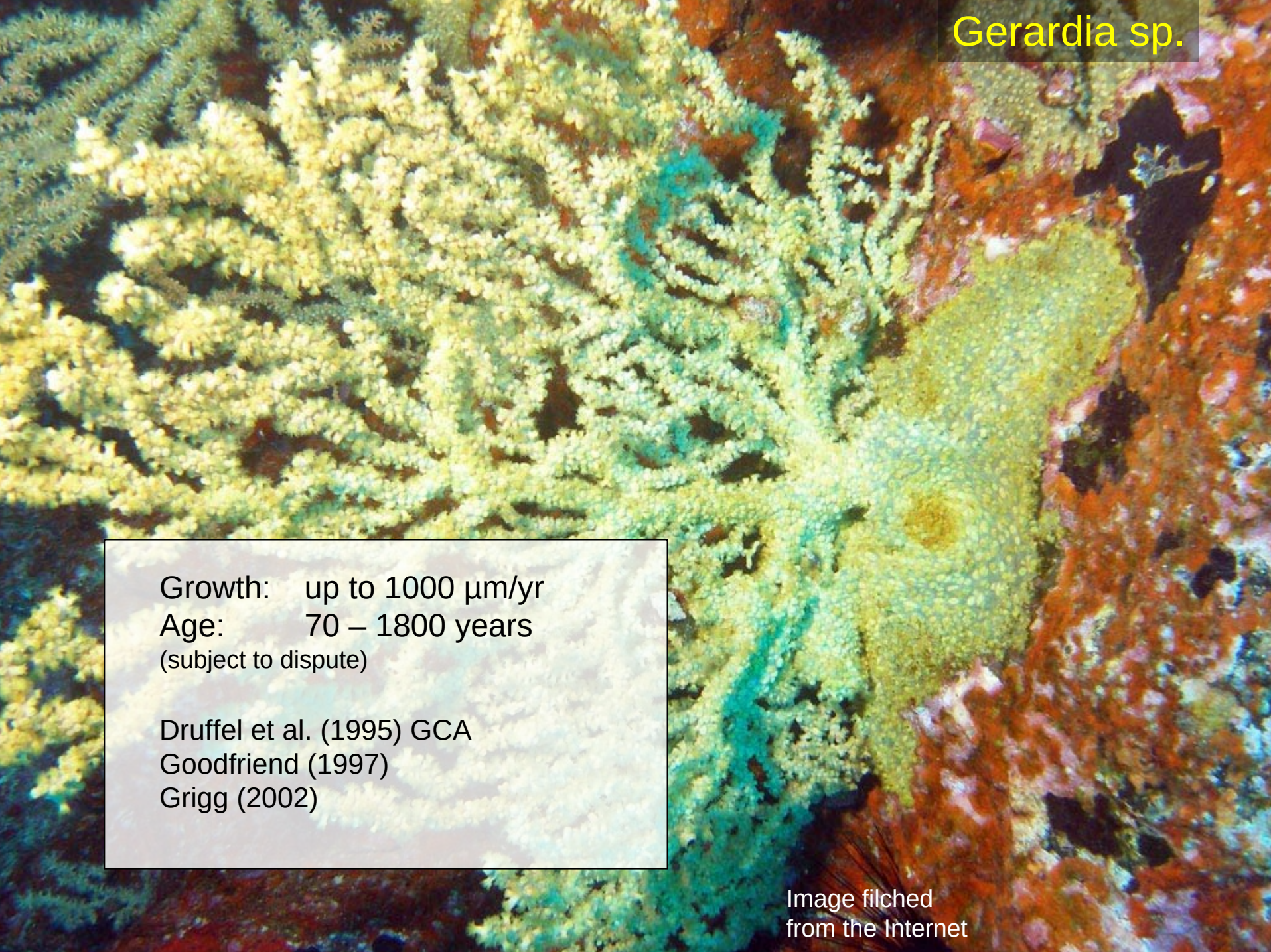
F. E. Moen

"Bamboo Coral" Isididae

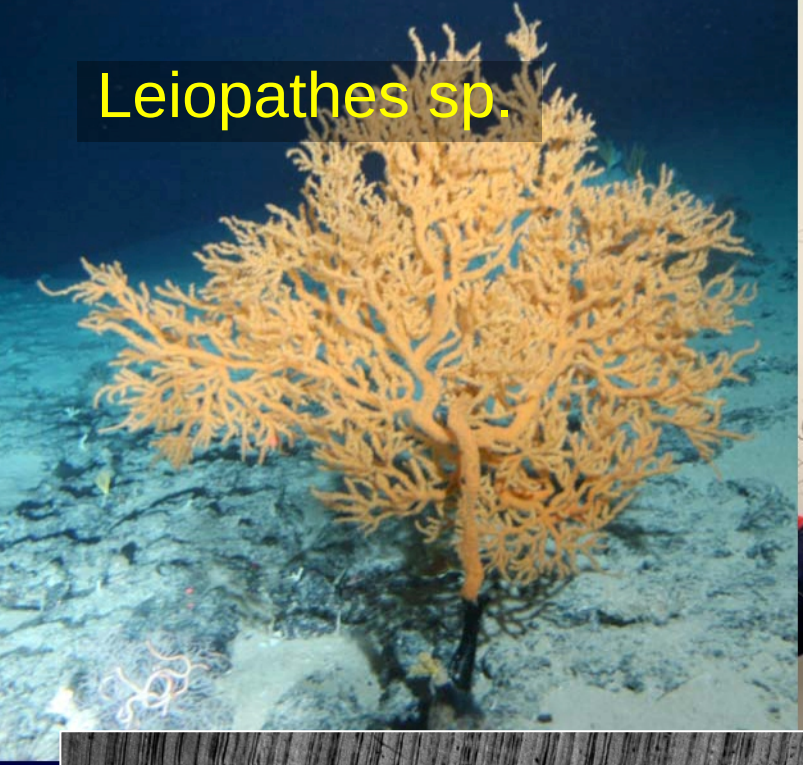


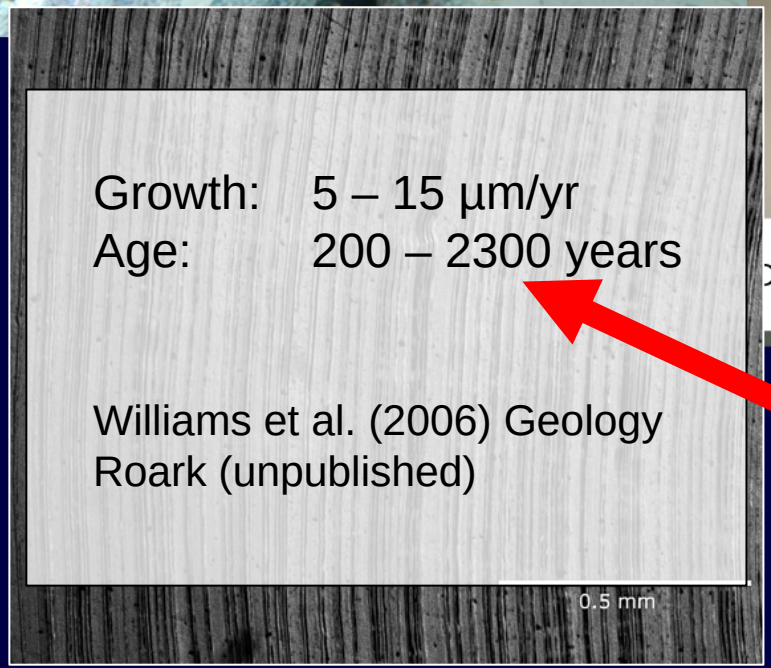
Growth: 35 – 290 µm/yr
Age: 43 – 305 years

Roark et al. (2005) GRL
Noe and Dullo (2006) Coral Reefs
Tracey et al. (2007) Bull. Mar. Sci.
Thresher et al. (2007) Bull. Mar. Sci.
Sinclair et al. (2008) GCA (in review)


Gerardia sp.
Growth: up to 1000 µm/yr
Age: 70 – 1800 years
(subject to dispute)
Druffel et al. (1995) GCA
Goodfriend (1997)
Grigg (2002)
Image filched
from the Internet

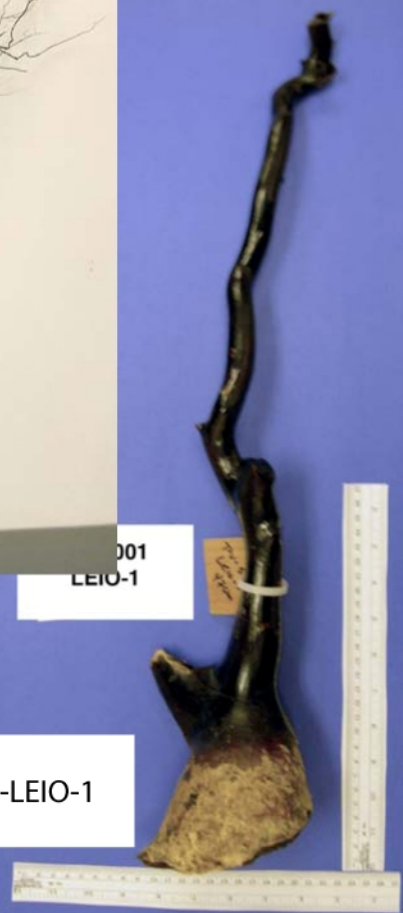
Leiopathes sp.





Growth: 5 – 15 µm/yr
Age: 200 – 200 years

Williams et al. (2006) Geology
Roark (unpublished)



What Can You Do With Them?

Organic Skeletons:

(eg. Leiopathes)

- Skeletons can be ‘peeled’ after KOH soaking or demineralisation by dilute acid.
- Analyse gorgonin for stable isotopes:
  - $\delta^{15}N$ – Sewerage
  - $\delta^{13}C$ – C source
- Trace Elements?
  - Nobody has tried.

Williams et al. 2006

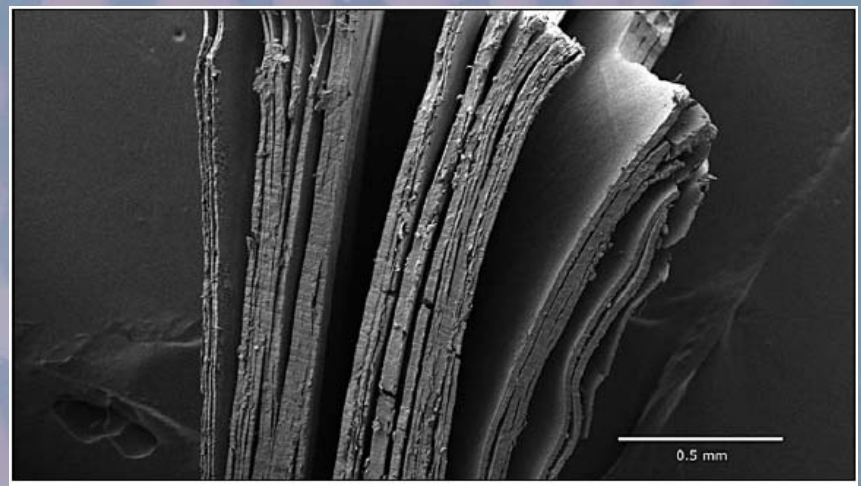
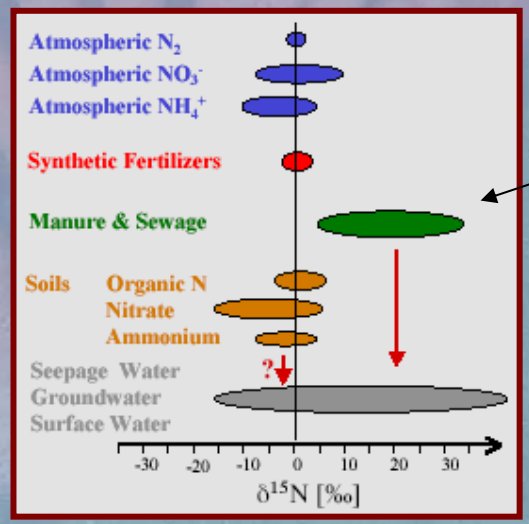
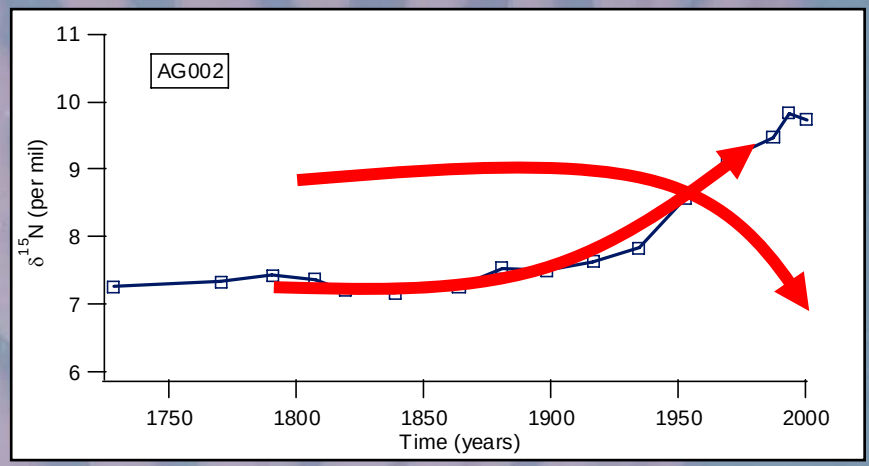


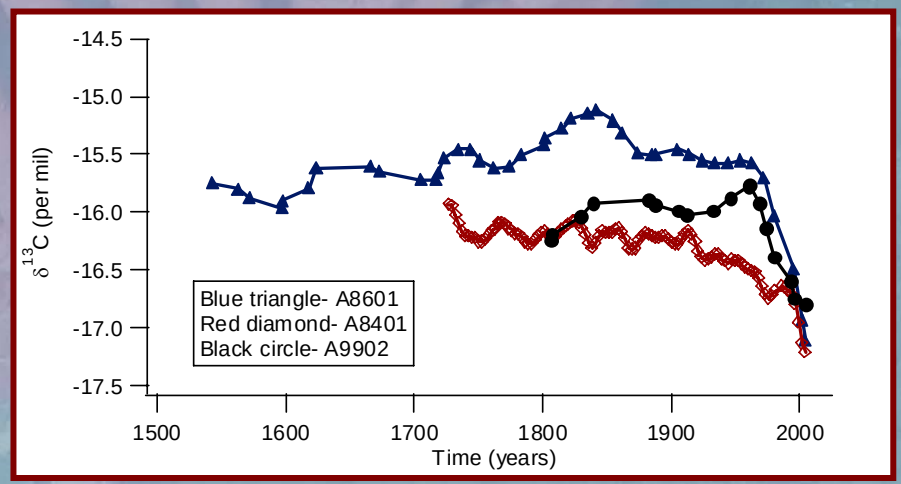
Figure 3. Cross section of specimen A8601 after KOH treatment.



Sewerage enriched in ^{15}N

Jason Newton, SUERC


AG002
11
10
9
8
7
6
δ^{15}N (per mil)
1750
1800
1850
1900
1950
2000
Time (years)

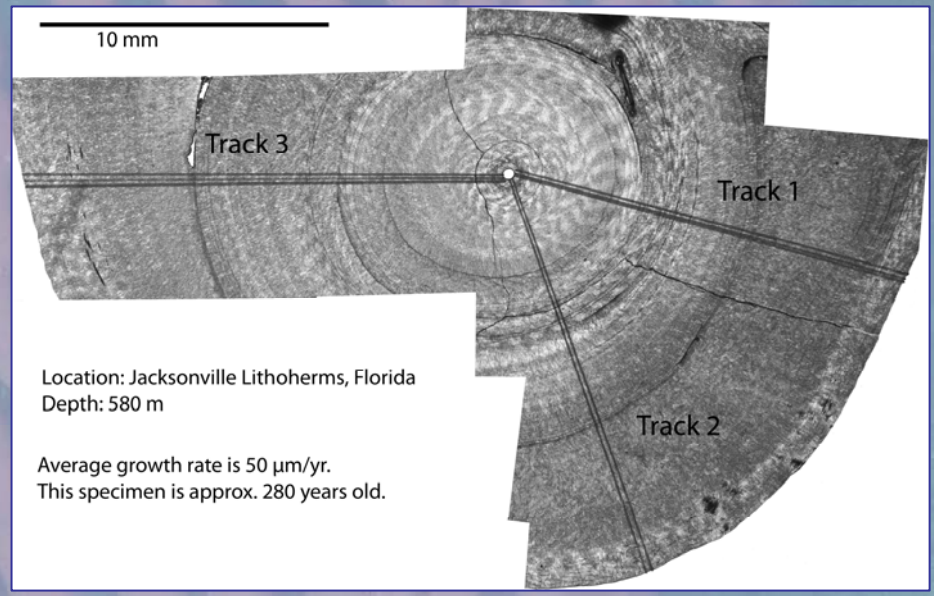

-14.5
-15.0
-15.5
-16.0
-16.5
-17.0
-17.5
δ^{13}C (per mil)
Blue triangle- A8601
Red diamond- A8401
Black circle- A9902
1500
1600
1700
1800
1900
2000
Time (years)

What Can You Do With Them?

Calcitic Skeletons:

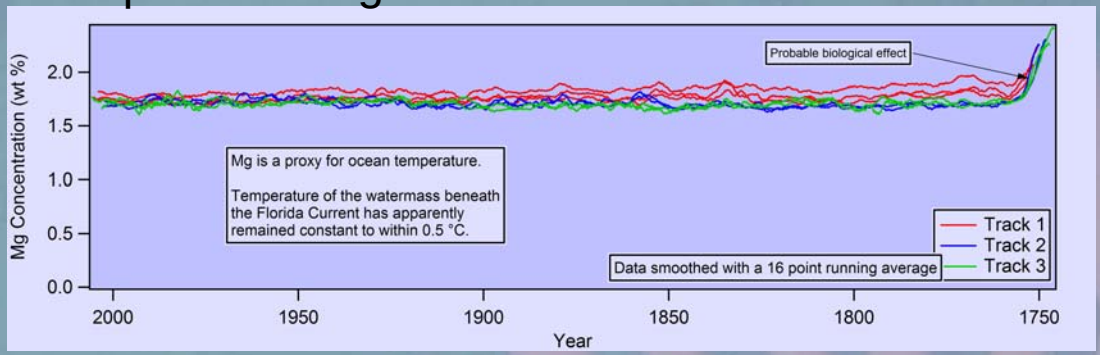
(eg. Keratoisis)

- Minor Element Analysis using Microbeam methods
  - (LA-ICP-MS, SIMS, etc)
  - Sr, Mg, Ba, Pb, Mn
- Physical Sampling
  - Low level metals
  - Isotope systems

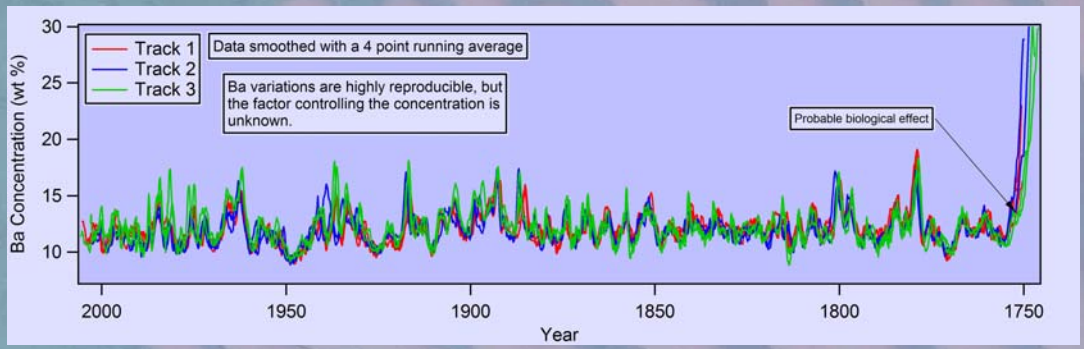


Sinclair et al. 2008 I, II (GCA – in review)

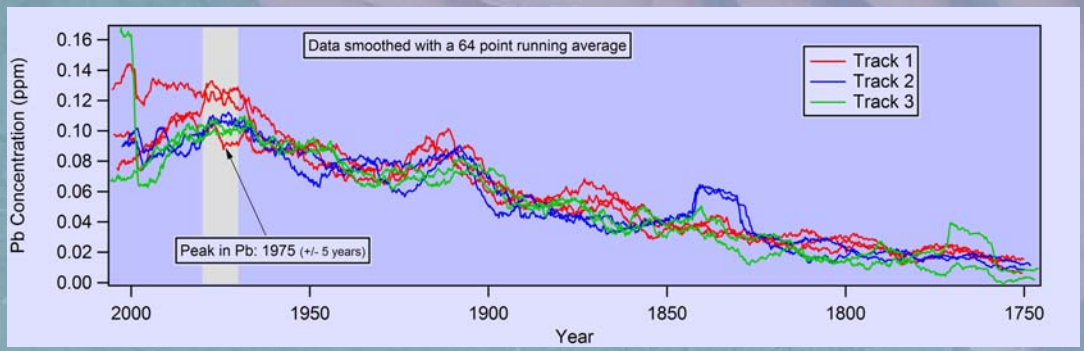
Temperature Signal – Stable Gulf Stream



Possibly productivity Signal



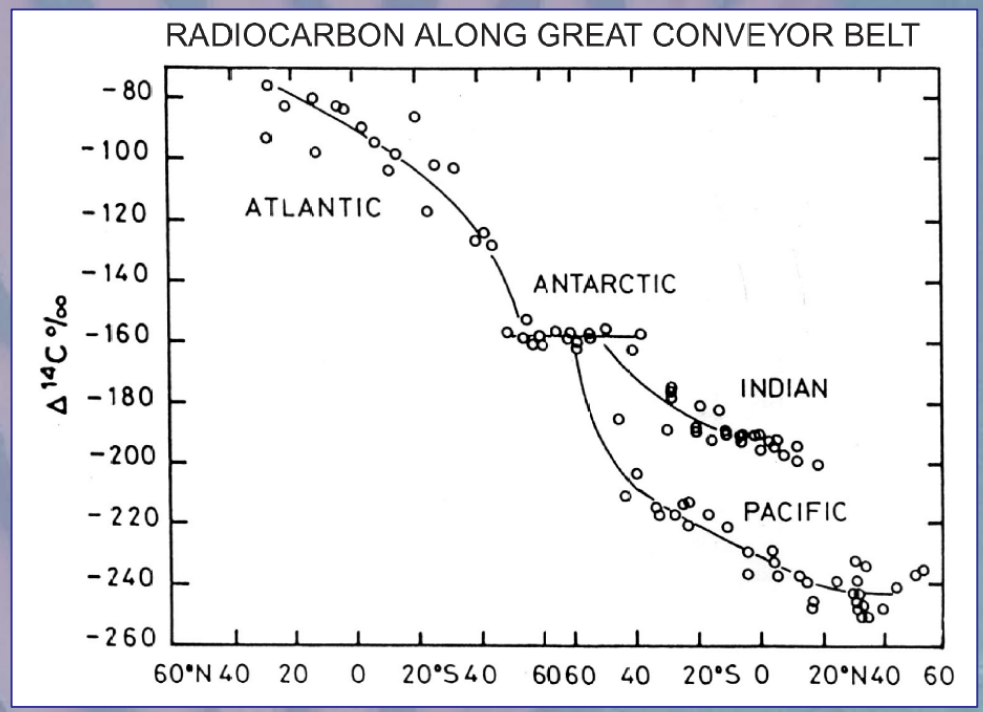
Industrial Pb



What Can You Do With Them?

All deep sea corals:

- Radiocarbon measurements
- Many applications: Norbert Frank to summarise!
- At the moment – probably the most useful oceanographic tracer (and one of the most expensive!)



From the North American TRACES talk by Jess Adkins

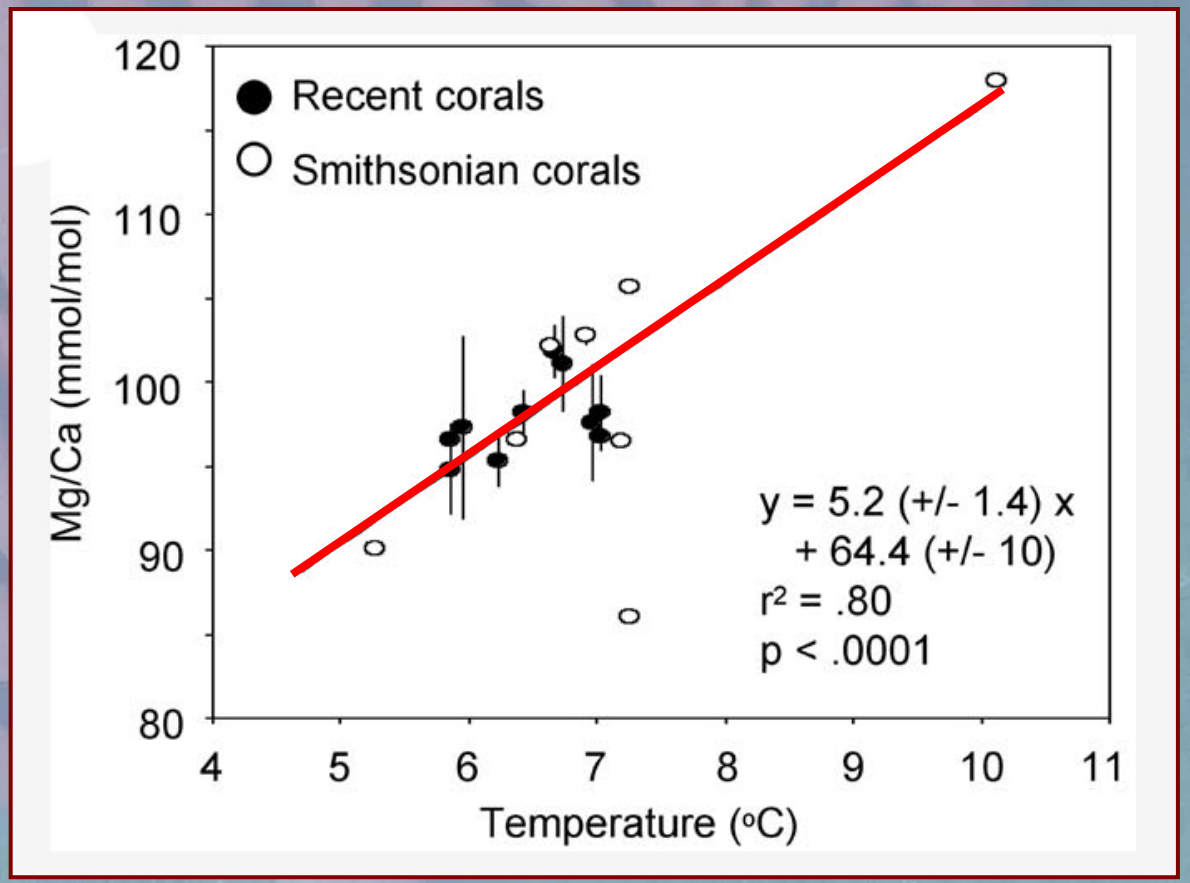
Temperature Calibration

Mg/Ca =
5 x T + 60

1 °C = 7 % change in Mg

Sherwood et al. (2005)

- Mg/Ca in calcite is T dependent
- 17 *Primnoa* colonies
- NW Atlantic Margin
- Calibrated to instrumental T

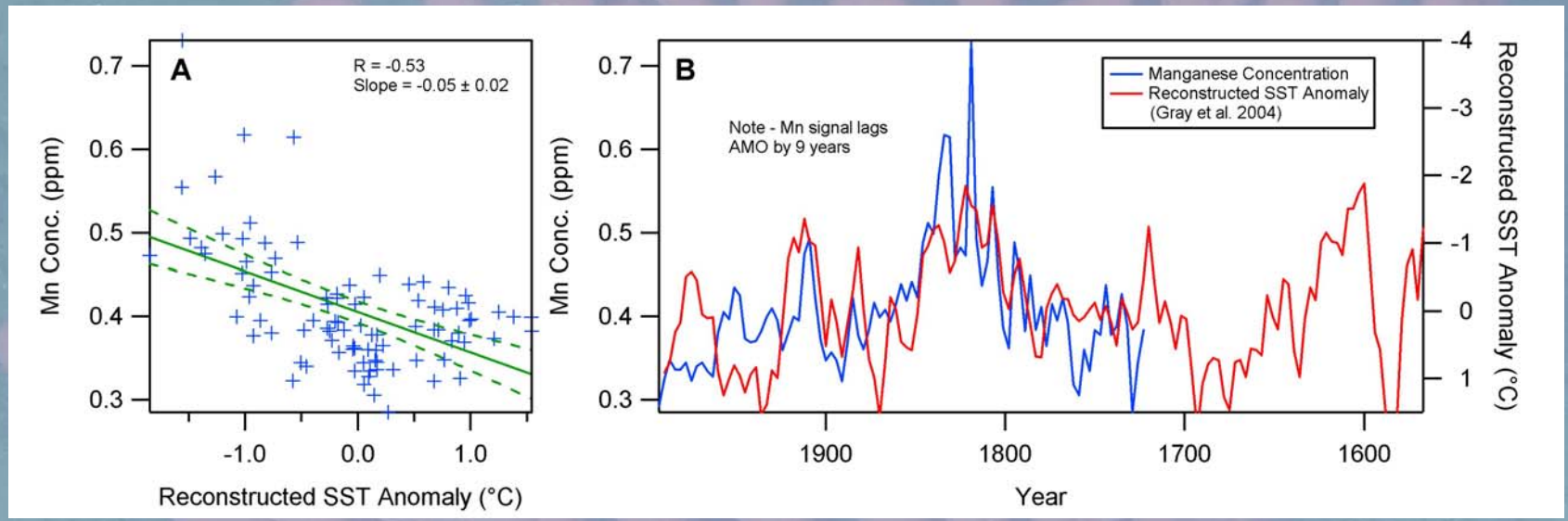


From Sherwood et al. (2005)

An Interesting Application

African Dust in Florida Corals (?)

Sinclair et al. 2008 (GCA – in review)



- Mn correlated with the Atlantic Multidecadal Oscillation.
- Droughts in the Sahel tend to occur when the Atlantic is cool (negative phase of the AMO).
- Leads to greater dust flux – rich in Mn.

Promising Proxies…

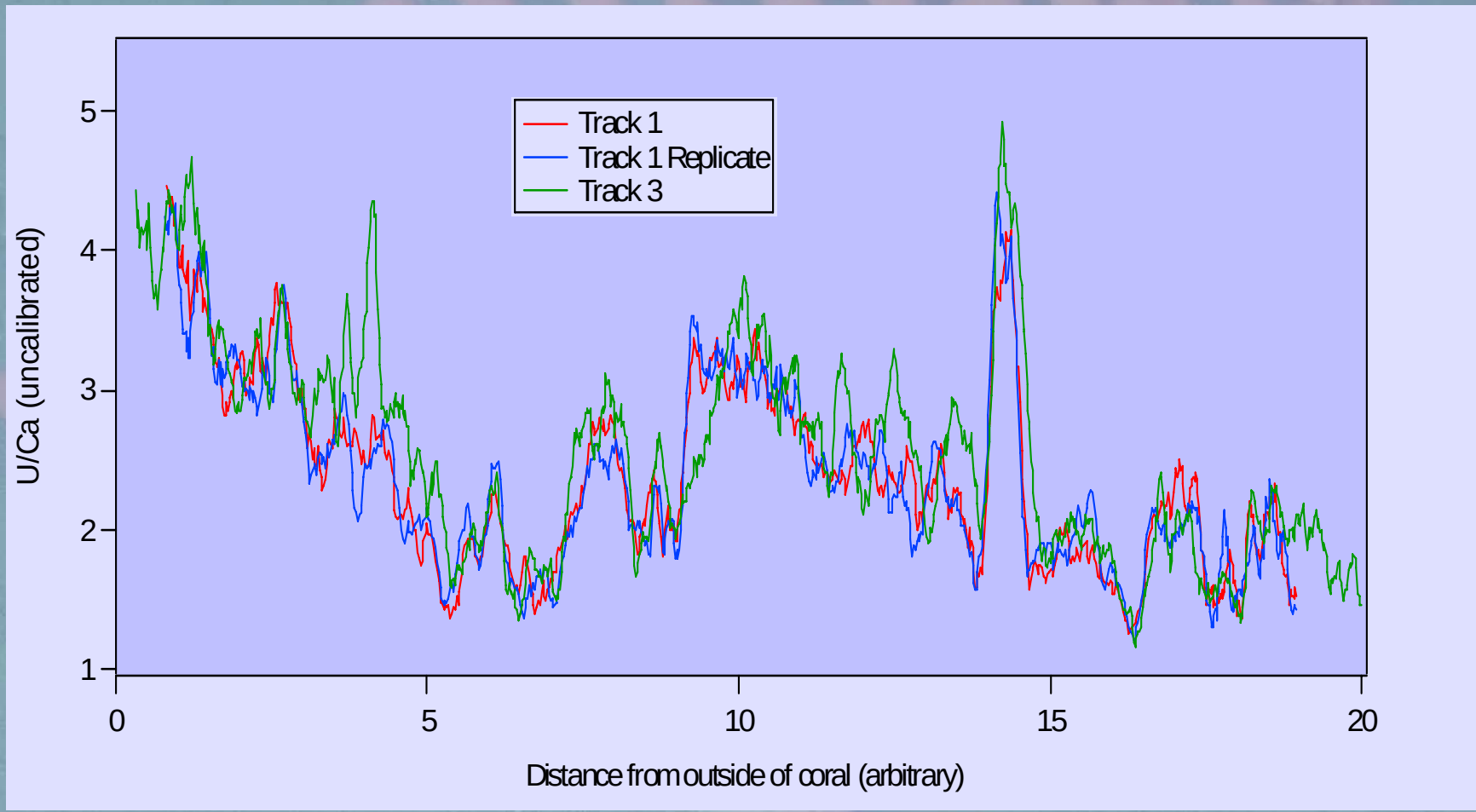
Octocorals are ideal for studying recent climate changes…

- Unfortunately...

(I did warn you)

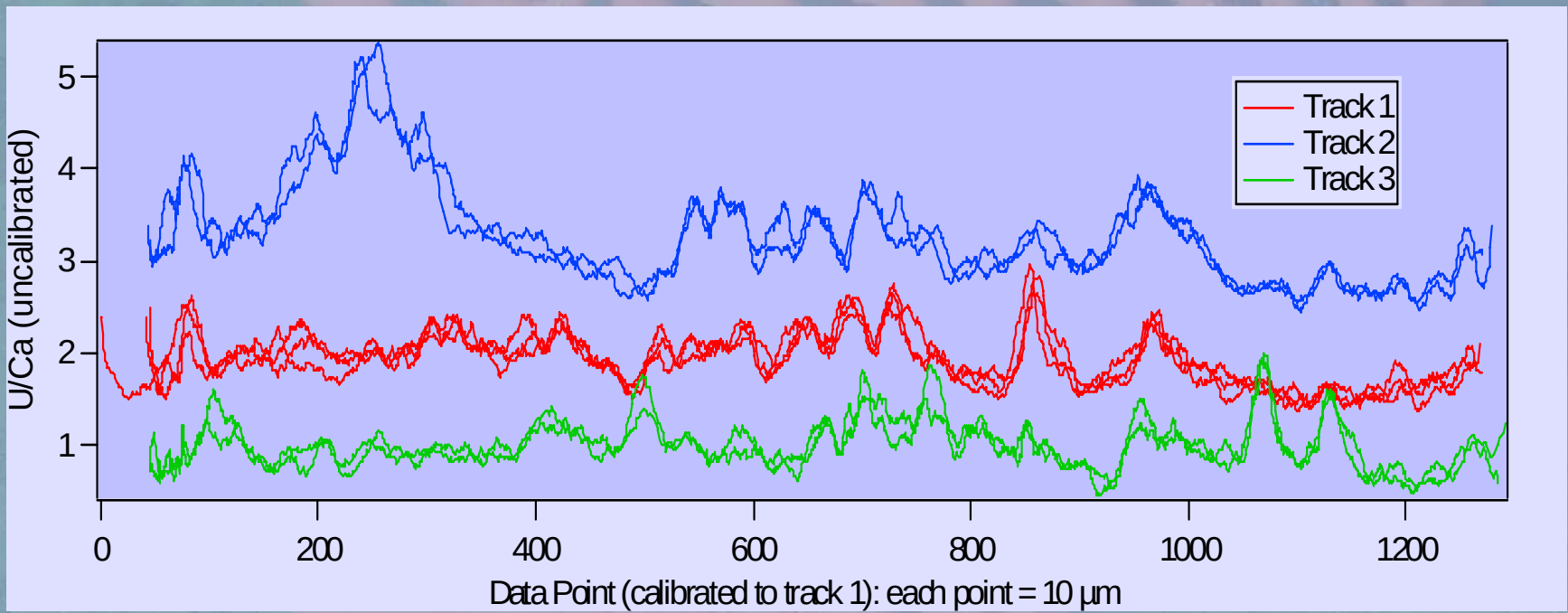
Complications

Uranium in Primnoa resedaeformis



Complications

Uranium in Keratoisis (note – tracks offset for clarity)



Outside
(youngest)

Inside
(oldest)

Imperfect Recorders

Deep sea octocorals do not always faithfully record environmental processes.

- Biological or diagenetic processes result in a heterogeneous skeleton.
- Where there is no reproducibility, there is no information.
- Need to test corals and reproduce records wherever possible.

Implications for Sampling

Octocorals are relatively scarce

- Opportunistic sampling
- Co-ordinate between biologists and geochemists

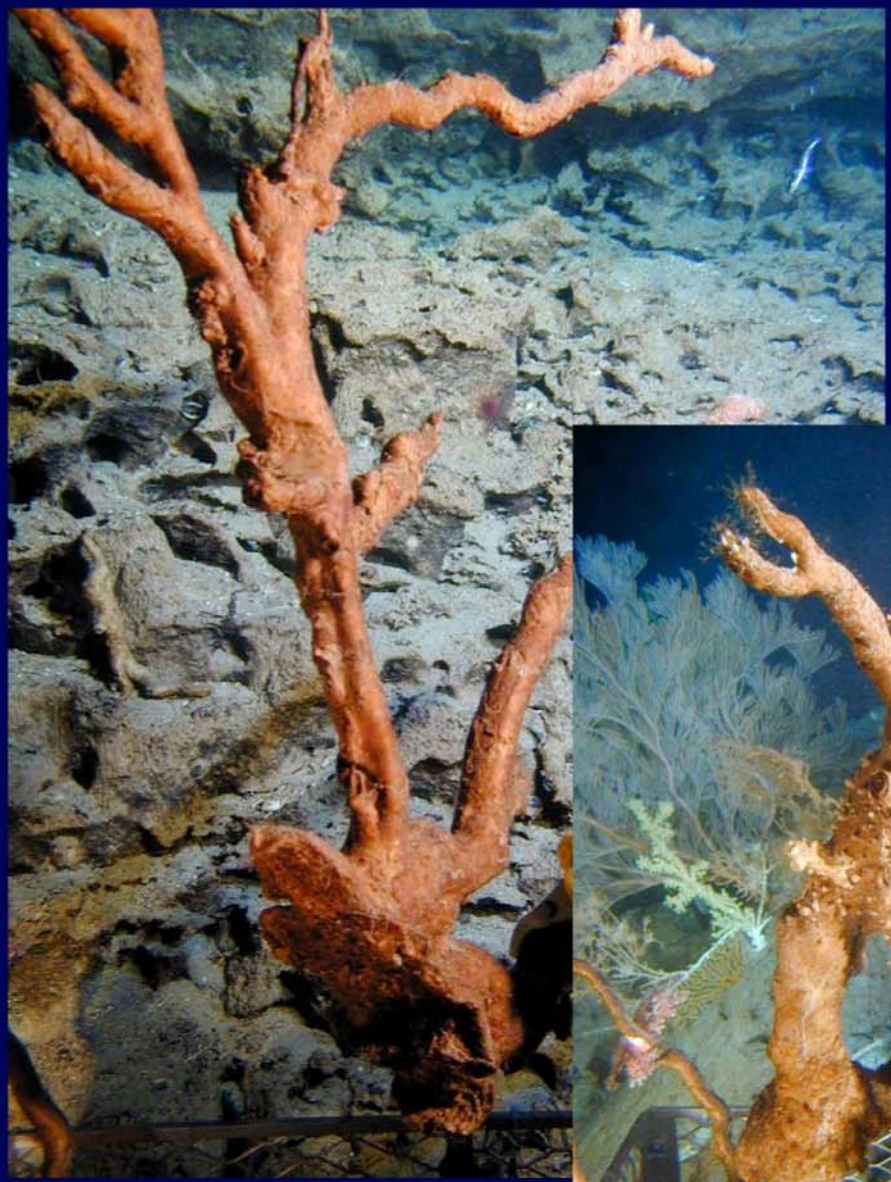
Can’t trust a single record

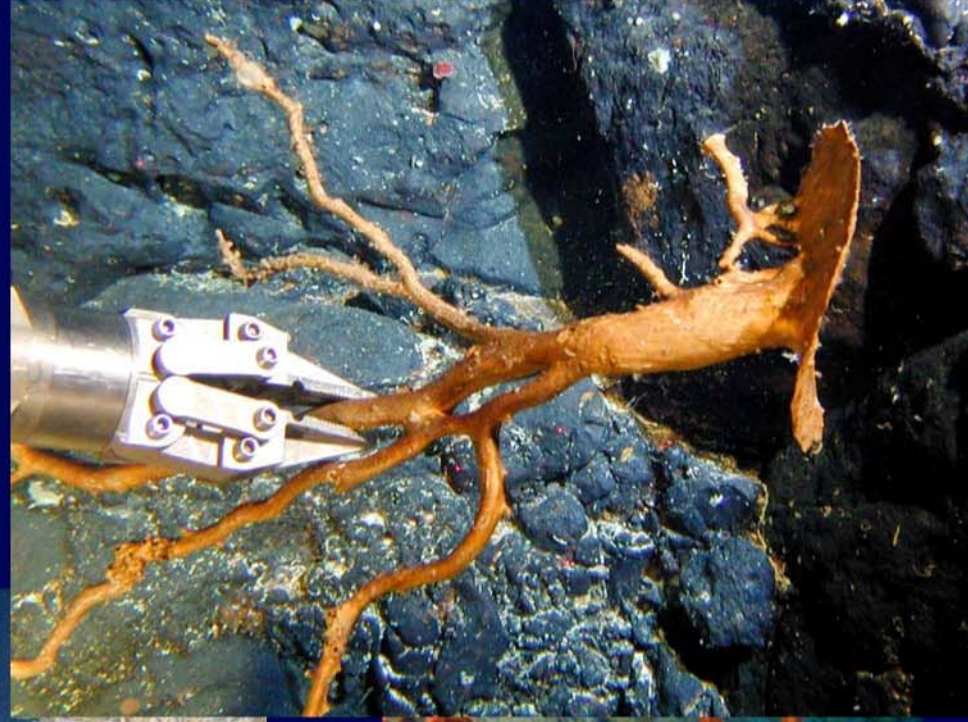
- Wherever possible take several samples
- Sample from a geographic transect
- (Ideal) Obtain organic and calcitic genera from the same location.

Most useful for studying modern climate

- Target regions where instability will be most evident
- Target regions of oceanographic significance: upwelling, downwelling, watermass boundaries, gateways, etc

Sub-fossil Gerardia





Wrap Up

Pollutants/Anthropogenic	
• $\delta^{15}N$	Nutrient source/sewerage
• $\delta^{13}C$	C source/Suess Effect
• Mn	Dust
• Pb	Industrial inputs
• Zn + metals	Pollutants
Oceanographic	
• Sr	Temperature? Growth?
• Ba	Nutrients + productivity?
• Sr isotopes	Temperature?
• Pb isotopes	Ocean watermass
• Nd isotopes	Ocean watermass
• Radiocarbon	Upwelling + water age

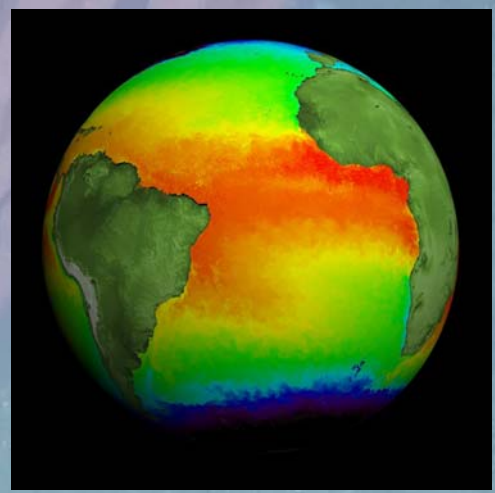
Wrap Up

Proxy Development Wish List

- Reliability testing
- Calibration
  - collections from environmental gradients
  - culturing
- Site monitoring + ocean observatories
- New proxies
  - Salinity proxy!
  - Nutrients/Productivity
- Co-ordinate geochemistry

Science Questions

- Ocean acidification
- Southern ocean
- Thermohaline shutdown
- Teleconnections – What drives what?



A Parting Thought…

Paleoceanographers salivate over the prospect of a 4000 year coral record…

- But…

  Does the science justify destroying an organism that has survived millennia?

Thanks To:

TRACES

SAMS

SAGES

Murray Roberts, Vikki Gunn + Many Others