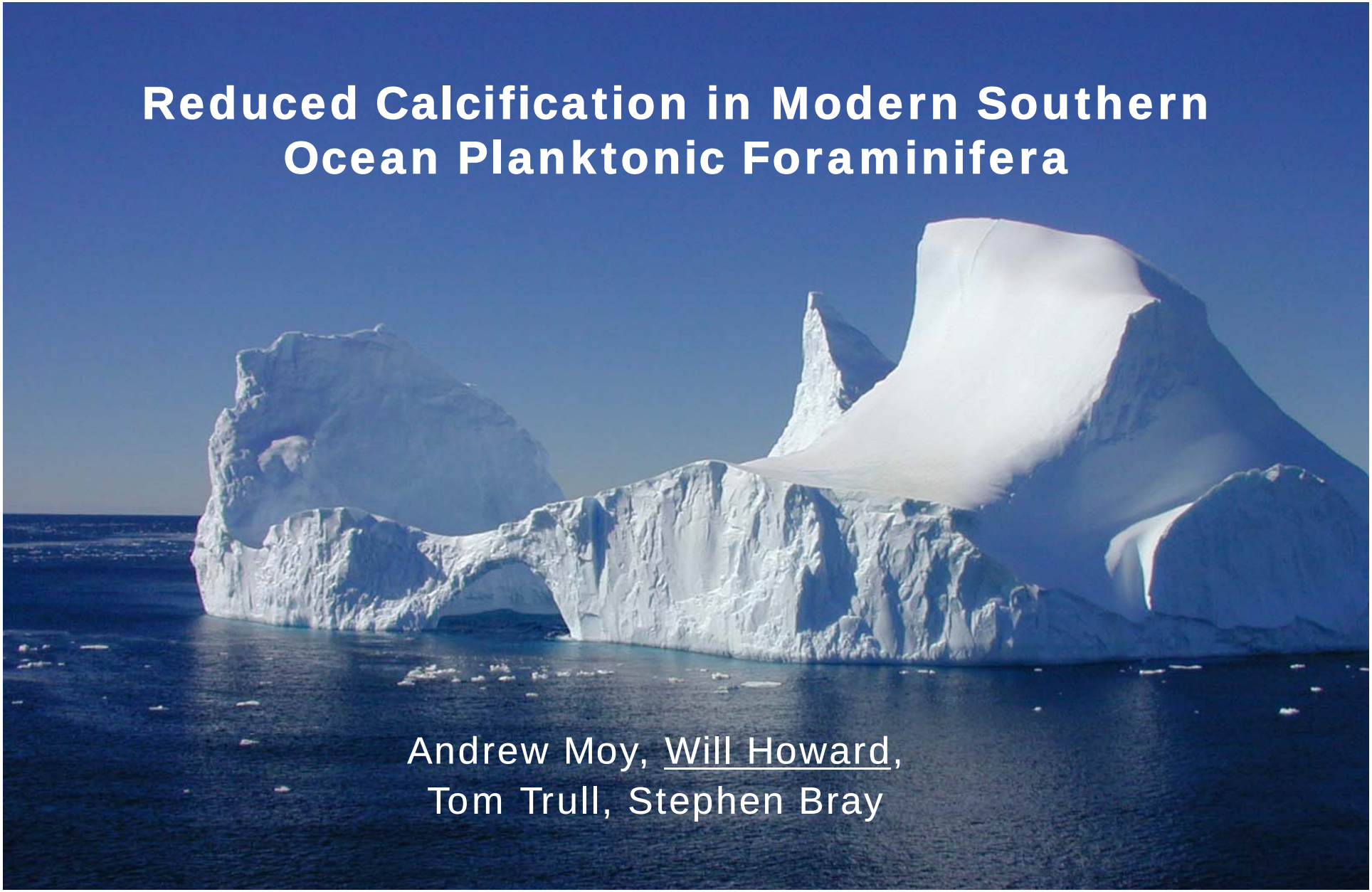
Reduced Calcification in Modern Southern Ocean Planktonic Foraminifera



Andrew Moy, Will Howard,
Tom Trull, Stephen Bray

Antarctic Climate & Ecosystems
Cooperative Research Centre

Australian Government
Department of Climate Change

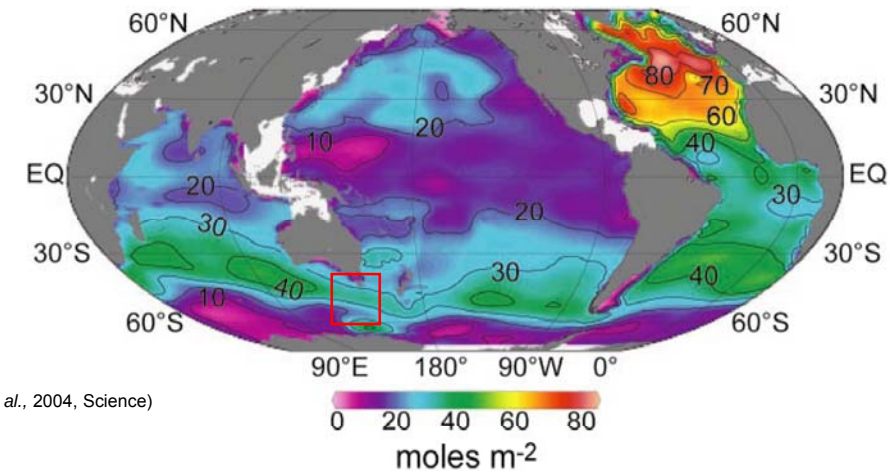
Motivation for Research Project

Most evidence for biological responses to ocean acidification based on laboratory experiments

Can we find field evidence for responses already underway?

Motivation for Research Project

Focus on the Southern Ocean as high anthropogenic CO_2 inventory region



(Sabine *et al.*, 2004, Science)

In our region:

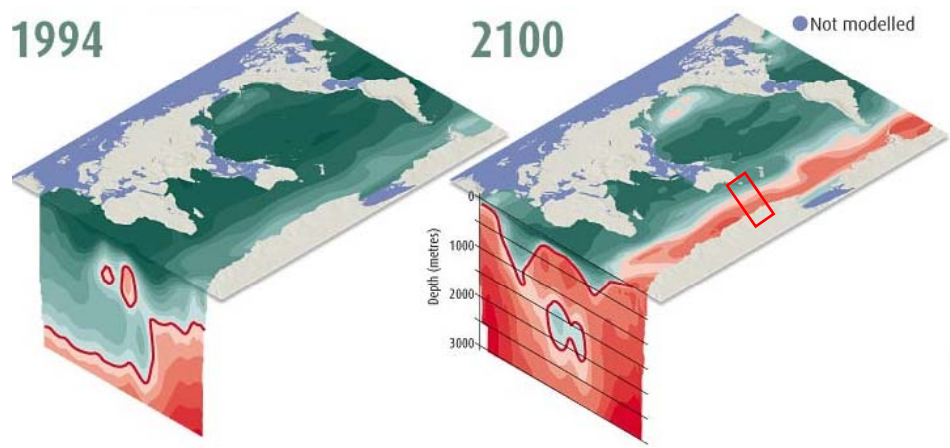
Anthropogenic CO_2 ~ 60 µM/kg

Δ [CO_3=] ~ -38 µM/kg

ΔpH ~ -0.15*

*** Mean surface ocean ~ -0.1**

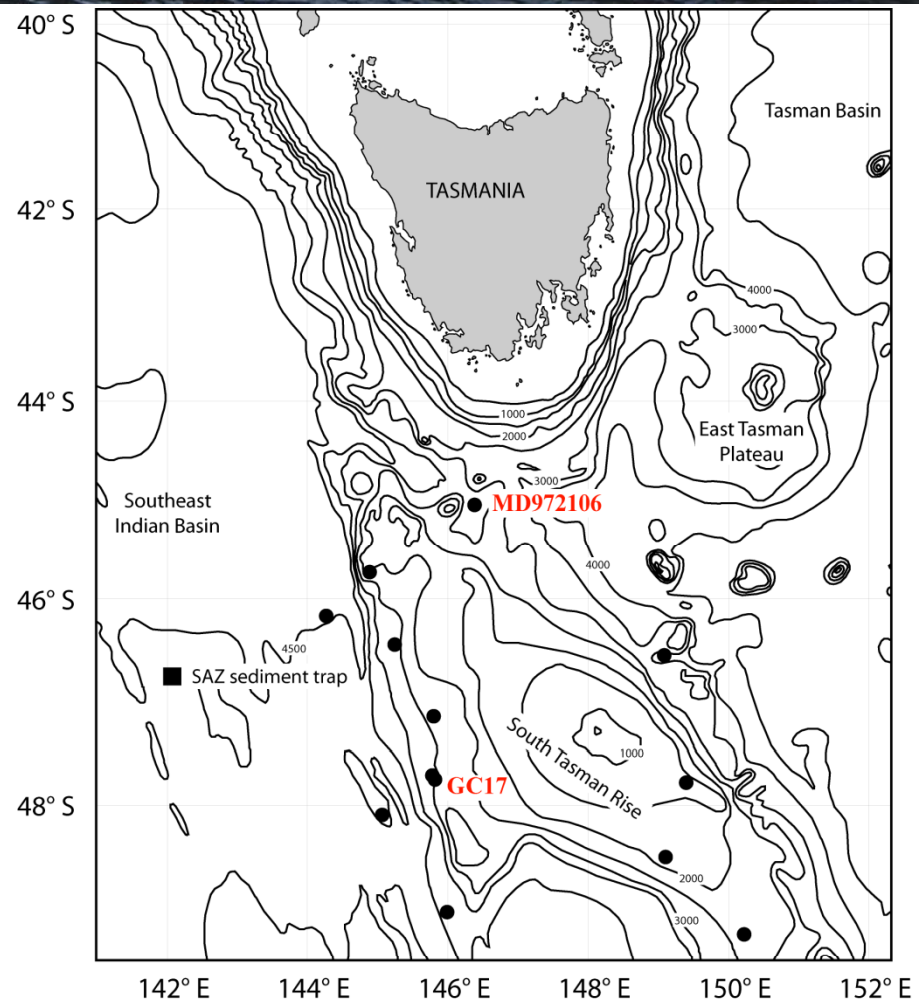
... and one of first regions to see low carbonate saturation levels



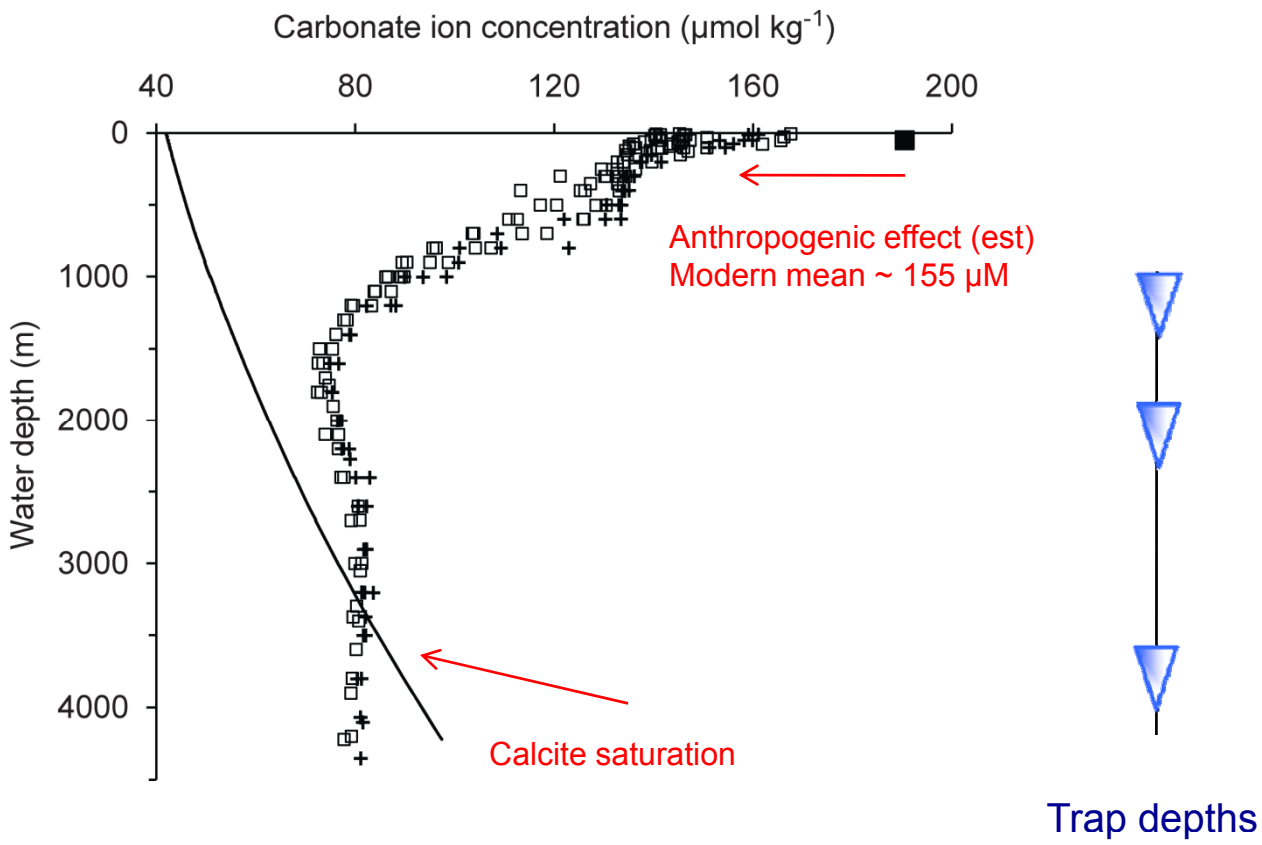
(Orr et al., 2005; New Scientist, 2006)

Study Setting

- SW Pacific sector of Southern Ocean
  - Crosses major surface-ocean gradients in carbonate chemistry & $CaCO_3$ production
  - Spans latitudes of maximum oceanic uptake of anthropogenic CO_2 (Feely *et al*. 2004)
- Several term long studies
  - Ocean chemistry, oceanography
  - Sediment trap studies (47°S)
    - Trap depth: : 1000, 2000, 3800m
    - Water depth: 4540m
- Sediment cores / core top samples
  - South Tasman Rise
  - 1200 to 4500 m below sea level
  - $CaCO_3$ preserved

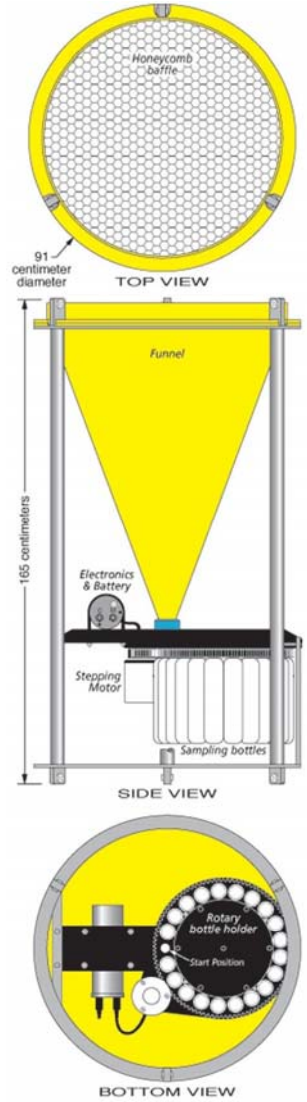


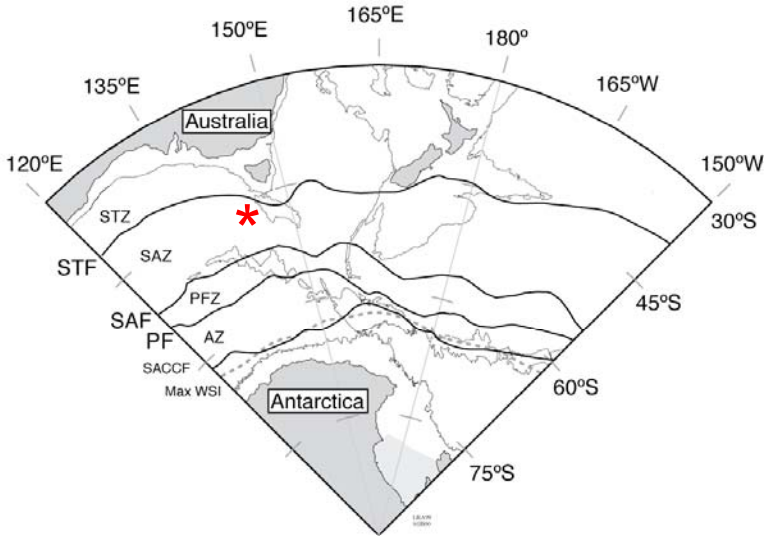
Study Setting

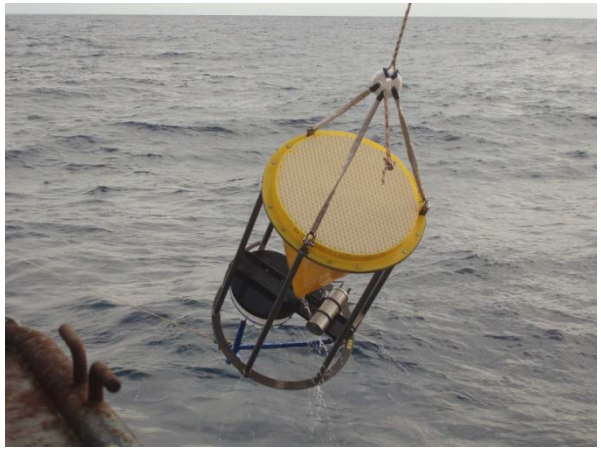


Southern Ocean sediment trap foraminifera

- Sediment Traps
  - 47°S, 142°E
  - 1000, 2000, 3800 m traps
  - 4540 m water depth
  - 1997/98 – 2004
  - each cup (21) treated with dense, buffered, biocide solution and open from 5 - 60 days



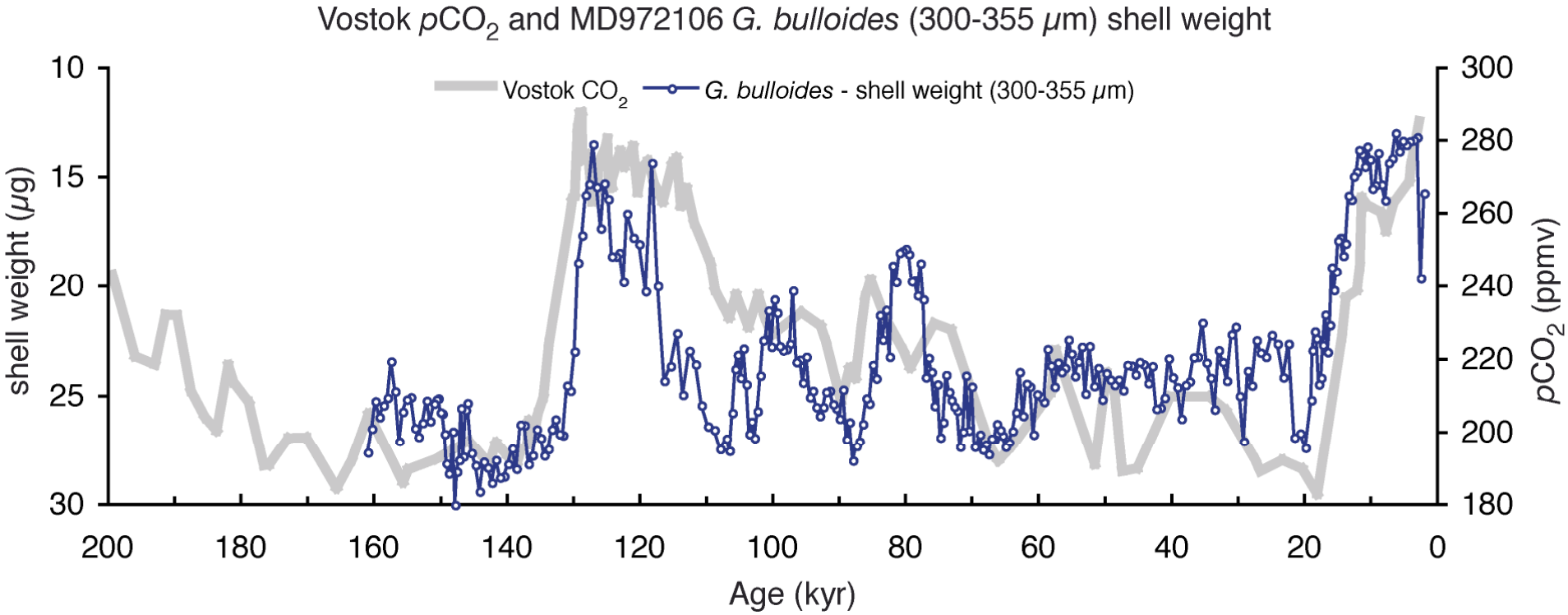




Approach

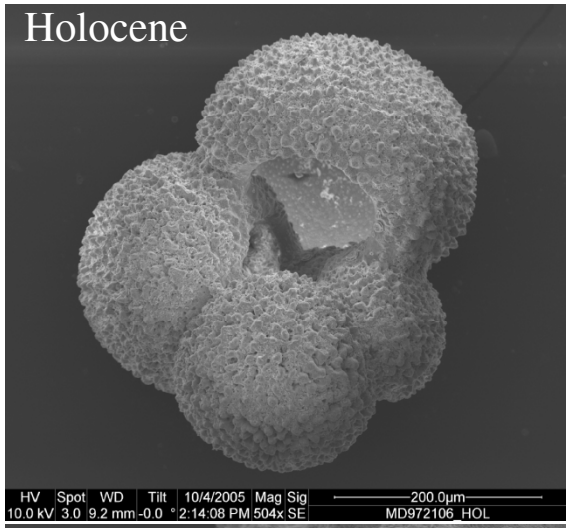
- Carbonate ion proxy - planktonic foraminiferal shell weights
  - Shell weights depend on the surface water [$CO_3^{=}$]
    - Shell weights increase with increasing surface water [$CO_3^{=}$] (Barker & Elderfield,2002)
- Shell weight determination
  - Planktonic foraminifera : *Globerigina bulloides*
  - 50 or more whole shells from a narrow size fraction (300-355µm)
- Last Glacial Maximum - Holocene shell weight change
  - LGM - Holocene CO_2 change ~100ppm
- Anthropogenic CO_2 effect - shell weight change
  - Holocene shell weights (pre-industrial base line)
  - Modern water column shell weights - SAZ sediment traps (industrial era)

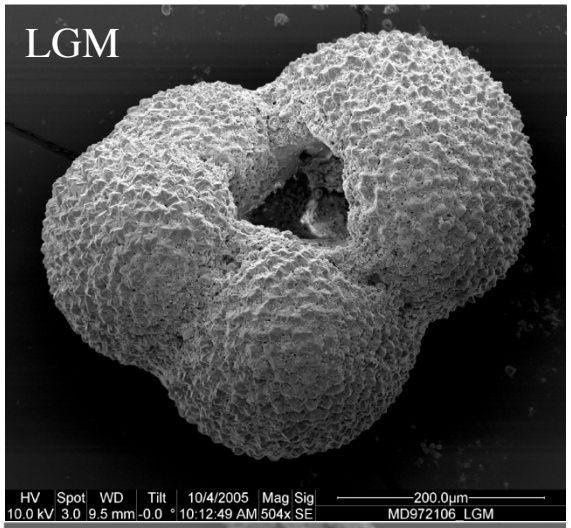
Glacial-Interglacial shell weight change (slightly north of our study area)

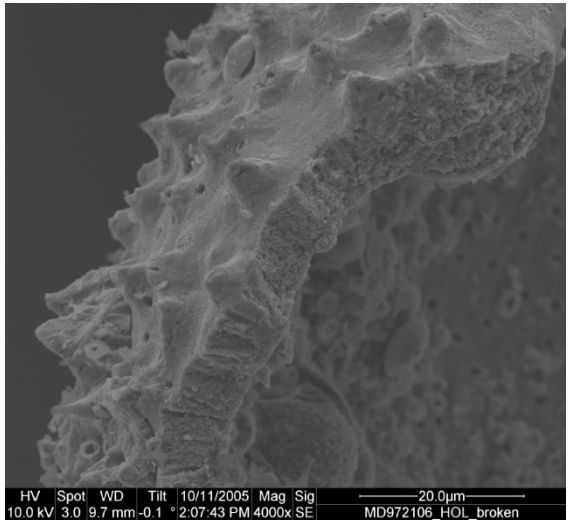


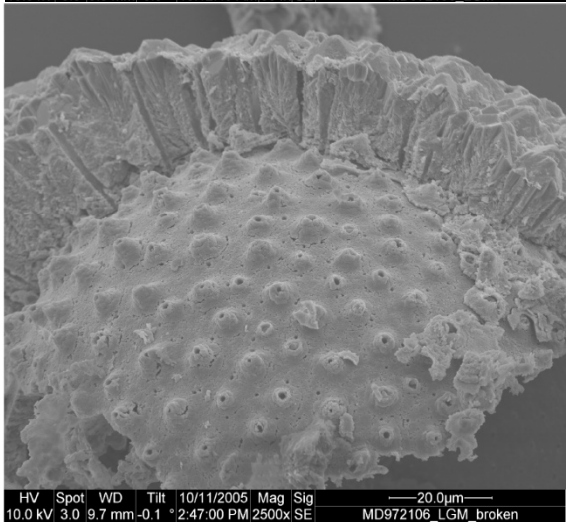
- Heavier shell weights during glacial intervals (low atmospheric CO_2)
- Lighter shell weights during interglacial intervals (high atmospheric CO_2)
- LGM - Holocene CO_2 change (~100ppm) - shell weight change: ~10μg (~34% reduction)
  - LGM – Holocene [$CO_3^{=}$] change (Moy et al. in prep)
    - ~75μmol/kg (estimated from shell weights)
    - ~80μmol/kg (estimated from $\delta^{11}B$)
- Similar temporal pattern and amplitude seen in North Atlantic (Barker & Elderfield, 2002)

LGM-Holocene Contrast









LGM-Holocene Contrast (in same water mass as sediment trap)

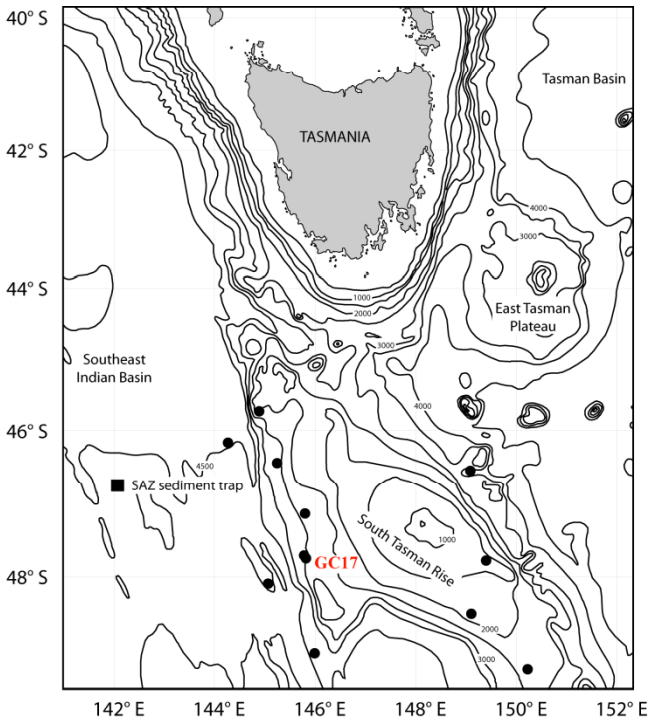
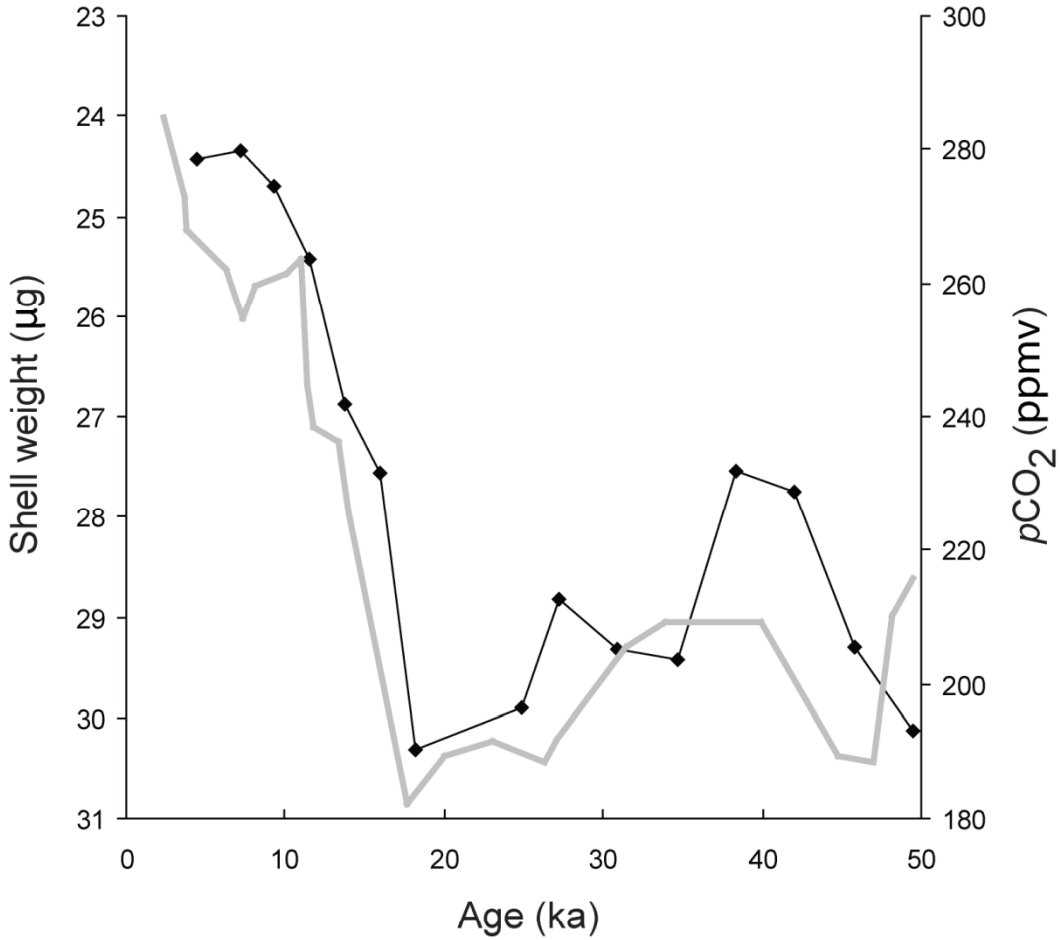


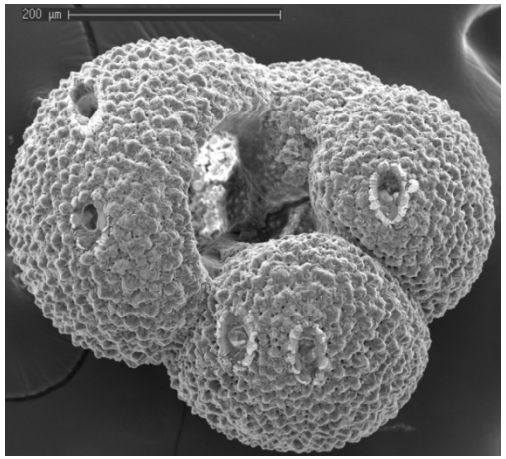
Figure 1



- LGM - Holocene CO_2 change (~100ppm) - shell weight change: ~6µg (~20% reduction)

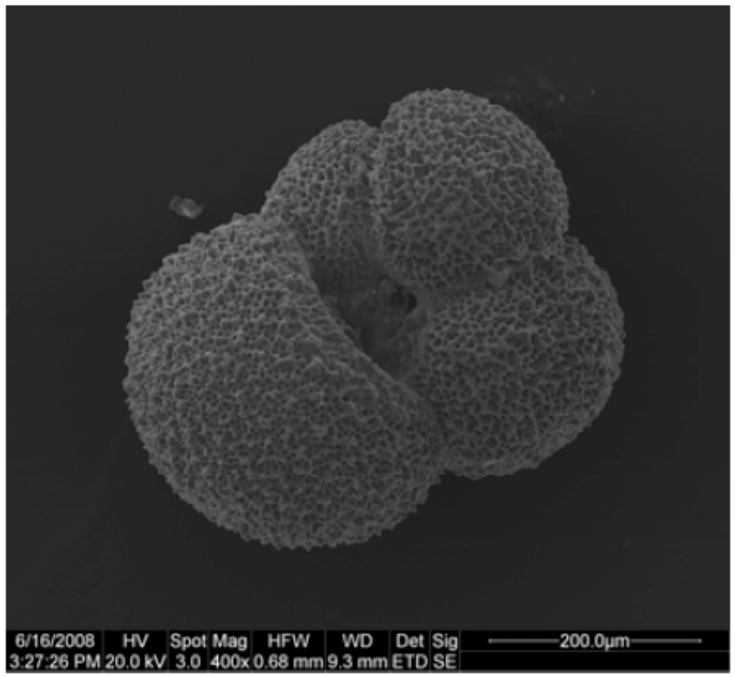
LGM-Holocene Contrast

- LGM shells heavier than to Holocene shells
- LGM shells - ‘crust’ like calcite, thicker shell walls (SEM)
  - Pores run through entire ‘crust’:
    - Indicates *G. bulloides* was alive when secreting calcite
- Other work completed
  - Laser ablation studies
    - Consistent trace metal ratios across LGM shell walls
  - Boron isotopes ($\delta^{11}B$) - proxy for seawater pH
    - Surface water palaeo-pH reconstruction
  - Indicates the glacial-interglacial shell weight variation
    - Changes in calcification
    - Direct response to changing carbonate chemistry

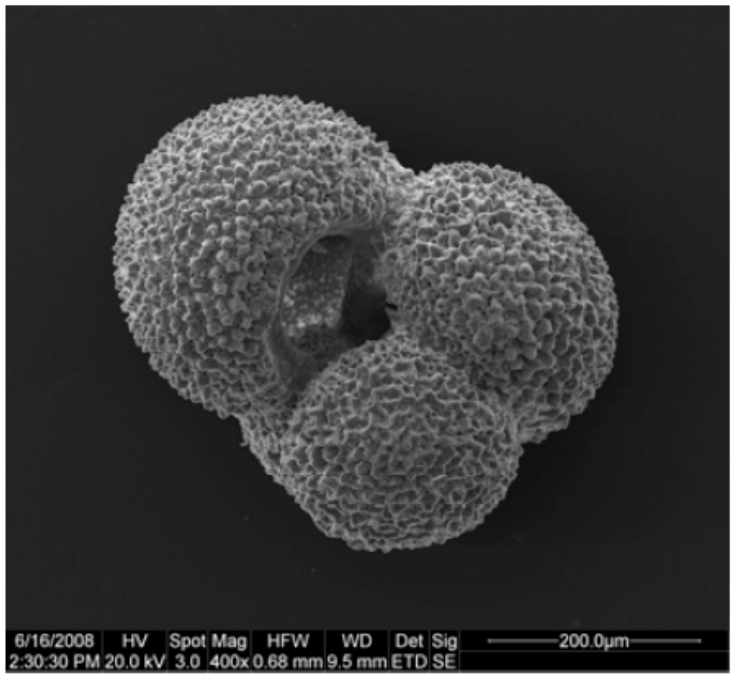


Holocene-Modern Contrast

Sediment trap

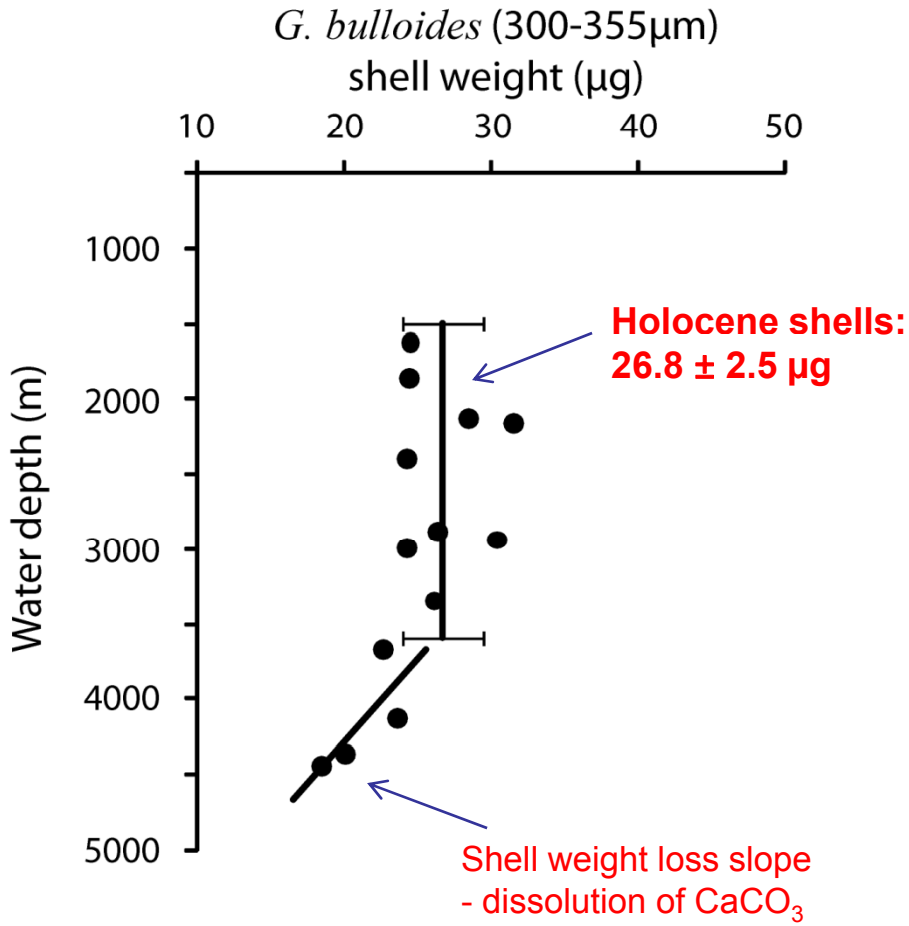


Coretop

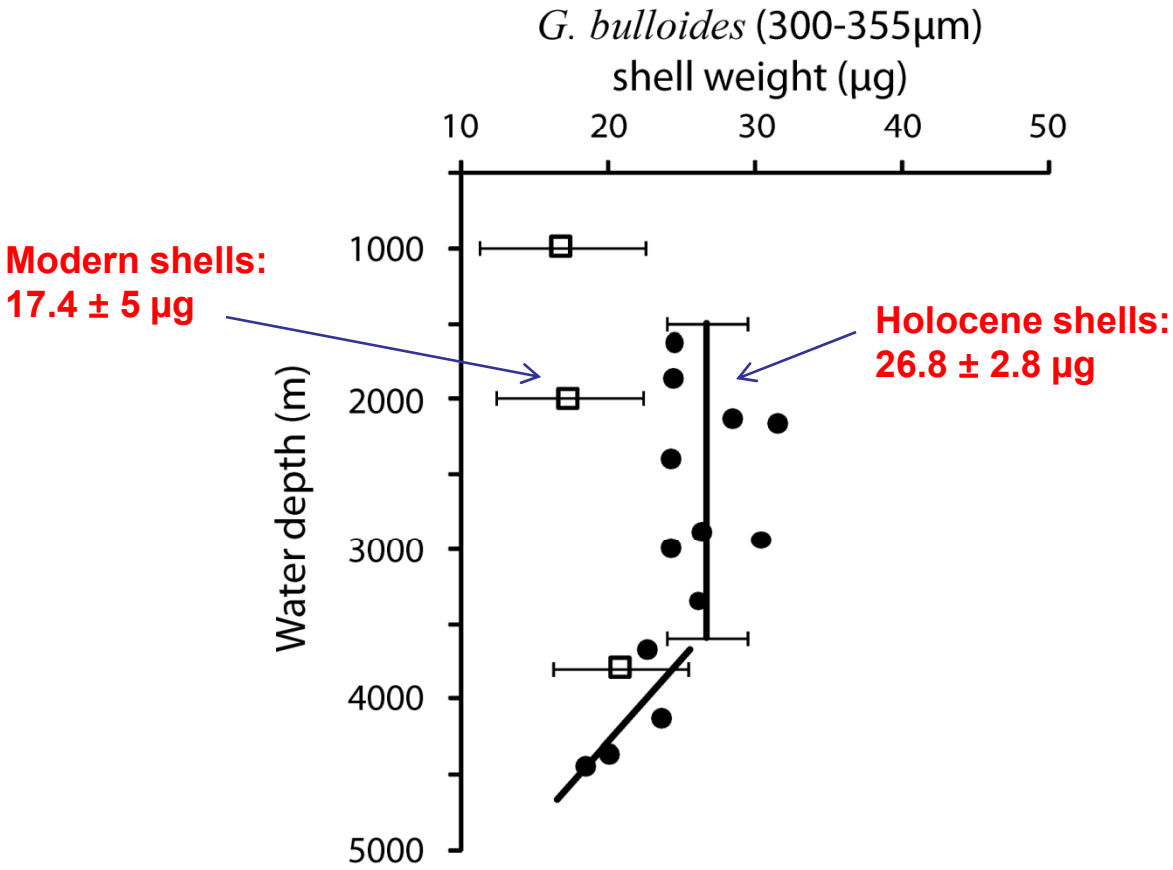


Sediment trap and Holocene *G. bulloides* both show irregularly lumpy calcareous deposits, broad interpore ridges and pore funnels with varying degrees of calcareous filling. There is no evidence of authigenic calcite overgrowths.

Holocene Shell Weights

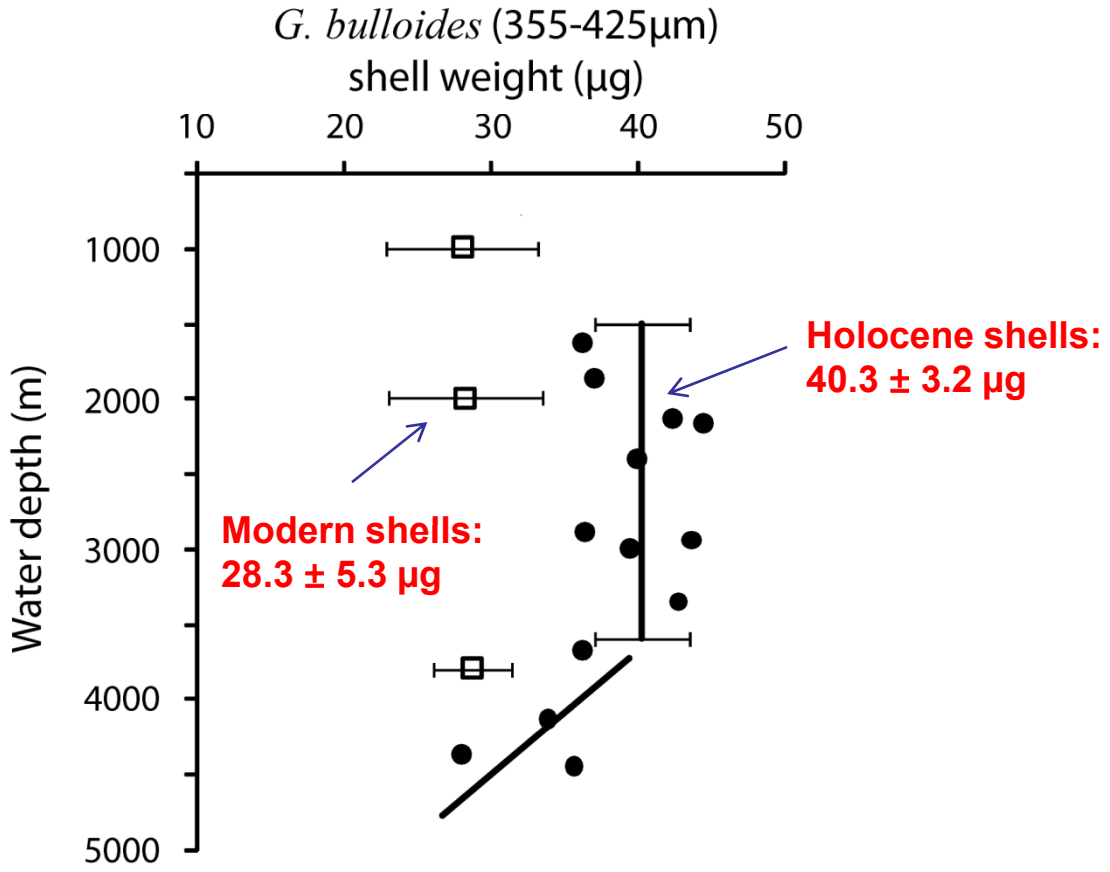


Modern Reduction in Shell Weight



- Modern water column shell weights compared to Holocene shell weights
  - **~35%** reduction in calcification (shell-weight) due to anthropogenic CO_2
  - Consistent with water-column anthropogenic CO_2 est. & core top calibrations
- Constancy of shell weights & shell fluxes (King & Howard, 2003) at 1,000m, 2,000m & 3,800m
  - Suggests water –column dissolution is negligible

Modern Reduction in Shell Weight



- Modern water column shell weights compared to Holocene shell weights (355-425µm)
  - **~30%** reduction in shell-weight

Alternative Hypotheses?

- Why do we think the Holocene-Modern shell differences are due to carbonate-ion effect, and not other drivers?
- We cannot rule out other variables, but we have some constraints:
- Temperature?
  - Sediment trap foraminiferal $\delta^{18}O$ overlaps coretop values (working on Mg/Ca)
  - Multivariate biotic structure of foraminiferal assemblage still similar to coretops
  - S.O. temperature changes still relatively small
  - Other variables? No apparent changes in modern fields, but little baseline data.

Summary

- LGM-Holocene shell weight studies
  - LGM-Holocene shell weight decrease
  - Shell weight variations - changes in calcification of foraminifera
- Anthropogenic CO_2 effect on shell weights
  - Sediment trap planktonic foraminifera shell weights
  - Holocene planktonic foraminifera (Pre-industrial base line)
    - ~30-35% reduction in shell mass (**first field observational study**)
- Implications for future marine carbon cycle
  - Global carbonate flux (foraminifera) ~1.3 - 3.2 Gt/yr
    - 23 - 53% open-marine $CaCO_3$ flux
  - Reduced $CaCO_3$ export by the surface ocean
    - C_{org}:$CaCO_3$ rain ratio
    - effectiveness of $CaCO_3$ as 'ballast' for C_{org} export

Thanks

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Co-Authors' Institutions:

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