Deglacial and Holocene Climatic and Hydrologic Variability in Tampa Bay, FL

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- Ethan Goddard, mass spec and ICP guru, Univ of South Florida

Many other Eckerd College students!
Motivation

- As greenhouse gases increase, global temperatures are increasing and will continue to increase.
- How quickly and to what extent will temperatures increase?
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- As greenhouse gases increase, global temperatures are increasing and will continue to increase.
- How quickly and to what extent will temperatures increase?
Paleoclimate data

- How did Central Florida climate respond during abrupt climate change?
- Focus on deglacial and Holocene
Tampa Bay

- Florida’s largest open-water estuary
- 400 square miles
- Drains 2,300 square miles
- Population surrounding bay ~2 million
- Excess nutrients and contaminants from cities and farms pollute the bay
- Need to understand how ecology, hydrology, chemistry, and sediments interact.

- During last glacial, sea level was ~130 m lower; coastline was ~150 miles offshore.
Lacustrine sediments

Restricted marine

11.3 ka BP

Lacustrine sediments

11.1 m

Open marine

21.1 ka BP

Age control by 25 $^{14}$C dates: sed rate $\sim$50 cm/ky

Tampa Bay core
MD-02 2579

11.1 m
Ostracode Geochemistry

\[
\text{Ca}^{2+} + \text{HCO}_3^- \rightarrow \text{CaCO}_3 \text{ (s)} + \text{H}^+ \\
\text{shell}
\]

Multi-proxy approach

- Mg/Ca: Evaporation – Precipitation
- Sr/Ca: Evaporation – Precipitation
- $^{18}$O: Temp, E-P, salinity, ground water

Multi-species approach

Periodic Table of the Elements
both species record similar relative changes in Mg/Ca and Sr/Ca; little species effect.

ΔMg/Ca are very similar to ΔSr/Ca; suggests they are proxies for same climate forcing.

relatively large synchronous changes in Mg/Ca and Sr/Ca; increase by x 2 from 530 to 370 cm.

decrease of 20% and 30% in Sr/Ca and Mg/Ca from 370 to 290 cm.

from 13.8 - 12.5 ka decrease of -2.2‰ in \(^{18}\text{O}\)

Age model: 19 AMS \(^{14}\text{C}\) dates

best fit smooth curve through data
20-30% decrease in Me/Ca from 23 to c. 17 ka BP suggests shift from drier glacial conditions to increased net moisture during deglacial.
Sharp increase in Me/Ca at 14.3 ka indicates drier conditions, followed by a return to lowest Me/Ca, indicative of wet condition at 14.1 ka.

Me/Ca in both species double over next 1,000 years indicating shift to drier conditions.

Me/Ca decrease by ~ 20% to end of record at 11 ka: increased net moisture during YD (Younger Dryas)

\(^{18}\text{O}\) influenced by E-P; mirror Me/Ca on centennial scale and confirm results.

Ice volume changes influence \(^{18}\text{O}\) over duration of record.
Changes in Thermohaline Circulation

- Reduced thermohaline circulation would lead to reduced heat transport from the tropics to high latitudes.
- Increased subtropical temps.
- Warmer summers lead to increased precipitation, consistent with the record of increased net moisture during the YD.
- Our record is coherent with Lake Tulane, 100 km east.
Abundance of Pine pollen indicates relative wet/dry conditions (Willard et al., 2007).

\[(\text{Me/Ca})_{\text{shell}} - \text{pollen age difference} = 180 \text{ yr} \ (\pm 68 \text{yr; n=8})\]

• 180 yr lag of vegetation response relative to the ostracode record confirms previous comparisons of vegetation responses to past climate change (e.g. Williams, et al 2002).

• Confirms theoretical predictions that vegetation changes should lag a stepped climate event by 100 - 200 years (Davis et al, 1985).
Holocene core: PC-75, VC-75

Benthic foraminifera: 
*Ammonia beccarii*

Shallow water benthic foram

Images from: 

Ten AMS radiocarbon dates
Foraminifera as paleotemperature proxy

Foraminiferal Mg = f (temperature)
  – Mg$^{2+}$ replaces Ca$^{2+}$ in CaCO$_3$ crystal structure
  – Relationship between Mg incorporation and T

\[
\left(\frac{Mg}{Ca}\right) = B e^{A \times T}
\]

– Species specific equation
– No calibration for A. beccarii
– Temperature sensitivity ~10% Mg/Ca per °C
PC 75

Warm

Cool

Mg/Ca (mmol/mol)

Age (Yr BP)

3 point running mean
Conclusions

• Transition from dry glacial to moist climate at 14 ka; shift to drier conditions at 13.0 ka progressing to greater net moisture during YD.

• Changes in meridional heat transport as a consequence of changes in thermohaline circulation explain wetter YD. Reduced THC leads to cooler N. Atlantic and warmer/wetter Florida.

• 180 yr lag of vegetation response confirms theoretical predictions of vegetation response to past climate change

• Holocene record indicates of warmer and cooler periods, coherent with MWP and LIA, respectively.
### Age Calibration

<table>
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<th>Core</th>
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<th>Material dated</th>
<th>Cal age yr BP midpoint</th>
<th>Error (yrs)</th>
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The strength and position of the Bermuda-Azores High pressure cell controls much of the seasonal climate changes. During the cool, dry winter, the Bermuda High keeps Florida dry. In the late spring and summer, the influence of the high weakens around Florida, and convective rains occur.

We propose 3 possible controls on net moisture in Florida:

1) the intensity of this annual cycle as controlled by orbitally induced variations in seasonal insolation;
2) millennial scale shifts in relative position of the Bermuda High and in the ITCZ;
3) changes in thermohaline circulation which affects meridional heat transport and thus temperature and precipitation in the subtropics.
What are controls for \((\text{Me/Ca})_{\text{shell}}\)?

- In the common case where lake water is saturated with respect to calcite, precipitation of low-Mg calcite removes Ca from solution, and increases the \([\text{Mg}]\) and \([\text{Sr}]\) since Mg and Sr are excluded from the calcite lattice. Thus dry conditions with evaporative concentration and low rainfall lead to an increase in \(\text{Mg/Ca}_{\text{aq}}\) and \(\text{Sr/Ca}_{\text{aq}}\) (Eugster and Jones, 1979).

\[
\text{CaCO}_3 \text{ pptn} \Rightarrow \downarrow (\text{Ca})_{\text{aq}} \Rightarrow \uparrow (\text{Mg})_{\text{aq}}, \uparrow (\text{Sr})_{\text{aq}} \Rightarrow \uparrow (\text{Mg/Ca})_{\text{aq}}, \uparrow (\text{Sr/Ca})_{\text{aq}}
\]

- We are not able to develop a quantitative relationship between changes in \(\text{Mg/Ca}\) or \(\text{Sr/Ca}\) and E-P, but instead use them to estimate relative changes in net moisture.

- \((\text{Mg/Ca})_{\text{aq}}\) and \((\text{Sr/Ca})_{\text{aq}}\) are controlled by evaporative concentration and low rainfall.

- Net moisture content (E-P) is the primary control on \((\text{Mg/Ca})_{\text{shell}}\) and \((\text{Sr/Ca})_{\text{shell}}\) in this marginal environment.
Results for modern estuarine mixing in Tampa Bay

• Mixing of fresh w/saline water results in large $\Delta$Mg/Ca$_{(aq)}$ , $\Delta$Sr/Ca$_{(aq)}$

• As S increases from fresh (0.2) to 5.5, Mg/Ca ↑ from 0.5 to 3.5 mol/mol; Sr/Ca ↑ from 2.6 to 6.6 mmol/mol.

• Non-linear mixing curve is predicted given conservative mixing between endmembers.

• This behavior is esp. significant at low salinities and is consistent with other Florida estuaries (Surge et al., 2002, Pillsbury et al., 2007, Dwyer et al., 2001).

• $\Delta$(Me/Ca)$_{(aq)}$ with changing salinity would affect incorporation of Mg and Sr into the calcite lattice, and thus the (Mg/Ca)$_{shell}$ and (Sr/Ca)$_{shell}$.

• High precipitation will lower salinity of brackish waters, and lower (Me/Ca)$_{(aq)}$
Background - Geochemistry

\[ \text{Ca}^{2+} + \text{HCO}_3^- \rightarrow \text{CaCO}_3 (s) + \text{H}^+ \]

- \( \text{Mg}^{2+} \) and \( \text{Sr}^{2+} \) substitute for \( \text{Ca}^{2+} \) in calcite lattice
- Partition coefficient, \( K_D \)

\[
K_D^m [Me]_{(T)} = \frac{m(\text{Me}/\text{Ca})_{\text{shell}}}{m(\text{Me}/\text{Ca})_{\text{water}}}
\]

- \( K_D [\text{Mg}] = f \text{ (temp)} \); \( K_D [\text{Sr}] \) = constant
- \( (\text{Mg}/\text{Ca})_{\text{shell}} \) is dependent on \( (\text{Mg}/\text{Ca})_{\text{water}} \) and temperature
- \( (\text{Sr}/\text{Ca})_{\text{shell}} \) is dependent on \( (\text{Sr}/\text{Ca})_{\text{water}} \)