Coastal Synthesis Workshop Agenda

Sediment Processes and Fluxes

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(Oregon State University)

Many Collaborators:

Themes of the talk:

**Theme I: Global/regional estimates of carbon burial in sediments**
- How reliable are they?
- Can they be compared to other flux measurements (e.g. atm/oce)?
- What are key variables and processes?
- Need observations and models of key processes controlling carbon sequestration

**Theme II: Issue of timescales**
- Carbon-centric benthic processes in coastal ocean range from hours to centuries
- Challenge in reconciling measurements at different timescales
- Role of events at all timescales (days to decades/centuries)

**Theme III: Spatial heterogeneity**
- Importance of sediment supply (burial/mineral surface area)
- Importance of OM flux (magnitude/composition)
- Importance of exposure to oxidants ([O2], mixing)
- Challenges for estimating fluxes at whole-margin, continent-wide scales
Theme I: Global/regional estimates of carbon burial in sediments
How reliable are they?

Global/Regional Carbon Budgets (Several Compilations)

Estimates of Carbon Burial $\rightarrow$ 0.2 PgC/y
Relatively small term
Importance of coastal margins/deltas
Can we compare them to other flux estimates?

Sarmiento & Gruber 2002
**Theme I: Global/regional estimates of carbon burial in sediments**

Can they be compared to other flux measurements (e.g. atm/oce)?

**Approach to Calculate Carbon Accumulation/Burial in continental sediments:**

\[
\text{OC Sediment Sink} = \text{OC content} \times \text{Accumulation Rate} \times \text{Area}
\]

Extremely crude approach that is likely not directly comparable to other estimates of carbon fluxes

**Reasons:**

1) Poor spatial coverage of OC distributions
2) Poor spatial coverage of accumulation rates
3) Accumulation rates calculated primarily with radio-isotopes
   Time span of these measurements is highly variable
   Most often used Pb-210 has a time span of decades
4) Most recent fluxes rates are not reflected in longer records (such as sediments)

➤ The scales of the burial flux estimates used in most global/regional studies are not comparable with other flux measurements (daily/monthly/seasonal/annual)
Hiatuses pervade the stratigraphic record at all scales ... Every attempt to measure a rate of accumulation must average together sediment increments and surfaces of hiatus. As the time span of measurement lengthens, longer hiatuses tend to be incorporated into the estimated rate. **Consequently, short term rates are systematically faster than longer term rates.**
Short term rates are systematically faster than longer term rates.

Accumulation Rates in Deltas

Time span of measurements:

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be-7</td>
<td>53.3 d (0.15 y)</td>
</tr>
<tr>
<td>Pb-210</td>
<td>22.2 y</td>
</tr>
<tr>
<td>C-14</td>
<td>5,730 y</td>
</tr>
</tbody>
</table>

Expected Delta Accumulation Rates:

<table>
<thead>
<tr>
<th>Isotope Used</th>
<th>Sed. Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be-7</td>
<td>~10 cm/y</td>
</tr>
<tr>
<td>Pb-210</td>
<td>~1 cm/y</td>
</tr>
<tr>
<td>C-14</td>
<td>~0.1 cm/y</td>
</tr>
</tbody>
</table>

Figure 4. Mean accumulation rates for terrigenous sediments on passive continental margins. a-a’: deltas (diamonds; 2,988 empirical rate determinations); b-b’: shelf seas (filled circles; 22,636); c-c’: continental slopes (crosses; 6,421); d-d’: continental rises and abyssal plains (squares; 10,821); e-e’: abyssal red clays (open circles; 2,215). Rates are averaged for logarithmically scaled windows of time span; there are five, non-overlapping windows for each order of magnitude.
Magnitude of Net Fluxes ‘Felt’ by Sediments accumulating at multiple decade timescales

Net Fluxes over the Anthropocene range from 1 Pg C/y in 1900 to 10 Pg C/y in 2000

These historically-varying fluxes result in very different flux rates at different time spans

<table>
<thead>
<tr>
<th>Time Span Years AD</th>
<th>Total C Added (Pg)</th>
<th>% of Total Increase</th>
<th>Calculated Flux (Pg C/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850-2000</td>
<td>440</td>
<td>100</td>
<td>2.2</td>
</tr>
<tr>
<td>1900-2000</td>
<td>398</td>
<td>90.5</td>
<td>4.0</td>
</tr>
<tr>
<td>1950-2000</td>
<td>290</td>
<td>66</td>
<td>5.8</td>
</tr>
<tr>
<td>1990-2000</td>
<td>88</td>
<td>20</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Sediment accumulating carbon at longer time spans would reflect lower flux rates than those measured in last 10 years
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  Carbon-centric benthic processes in coastal ocean range from hours to centuries
  Challenge in reconciling measurements at different timescales
  Role of events at all timescales (days to decades/centuries)

Theme III: Spatial heterogeneity
  Importance of sediment supply (burial/mineral surface area)
  Importance of OM flux (magnitude/composition)
  Importance of exposure to oxidants ([O2], mixing)
  Challenges for estimating fluxes at whole-margin, continent-wide scales
Theme I: Carbon burial in sediments
– Key Variables

- Sediment supply (burial/mineral surface area)
- OM flux (magnitude/composition)
- Exposure to oxidants (O2, metal-oxides, etc.)
- Time scale!
Theme I: Global/regional estimates of carbon burial in sediments
Environmental processes controlling key variables

Benthic processes controlling/affecting carbon sequestration

Physical
- Transport, deposition, resuspension, biological mixing of carbon-relevant materials (organic matter, sediment, dissolved oxygen)

Biogeochemical
- Biological production, degradation, sorption/desorption of organic materials

Observations and models for each type of process exist
- i.e., Sediment transport
- i.e., Sediment diagenesis

Observations and models that link Physical – Biogeochemical processes specifically are needed.
Theme II: Issue of timescales
Forcings affecting benthic carbon processes in coastal ocean range from hours to decades

Wave event (hours) to Upwelling (weeks) to El Nino/La Nina (years)

Example: Benthic O2 Consumption (Clare Reimers)

Oxygen Flux by Eddy Correlation Method (after Berg et al. 2003)

Traditional Porewater Diffusion Method
Example of Time series data (currents, waves, oxygen and flux)

Burst 33 02:45-03:00

\[ \Sigma (V_z C' dt) \]

OE = -15.4 mmol m\(^{-2}\) day\(^{-1}\)
Eddy Flux vs. Diffusive

EC Fluxes

Using Fick’s Law

DOU = -3.2 mmol m\(^{-2}\) day\(^{-1}\)

mean

-4.2\(\pm\)2.2
Example of seasonal vs. decadal accumulation rates off Atchafalaya River (Allison et al. 2000; Gordon et al., 2001)

- Seasonal vs. long-term (100 yr time span) accumulations vary by an order of magnitude

Approach:
- Collected cores at different locations during different cruises (I-IV) of contrasting oceanographic and discharge conditions
- Measured accumulation rates using radionuclides of contrasting half-lifes (i.e. different time spans; Be-7 vs. Pb-210)
### Ranges in seasonal vs. decadal accumulation rates

<table>
<thead>
<tr>
<th>Location</th>
<th>Seasonal Sed. Rate</th>
<th>Seasonal Sed. Rate</th>
<th>Long-Term Sed. Rate (~100 y timescale)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Q</td>
<td>Low Q</td>
<td></td>
</tr>
<tr>
<td>Inshore</td>
<td>10 – 14 cm/y</td>
<td>4 – 6 cm/y</td>
<td>0.5 – 0.7 cm/y</td>
</tr>
<tr>
<td>Offshore</td>
<td>2 -4 cm/y</td>
<td>1 – 4 cm/y</td>
<td>0.1 – 0.4 cm/y</td>
</tr>
</tbody>
</table>

![Graphs showing the data](image-url)
By combining measured sedimentation rates with measured organic carbon distributions at different spatial/temporal timescales, we can estimate short- and long-term carbon burial rates (Gordon et al., 2001).

Order of Magnitude Differences in Seasonal (months) vs. Long-term (decades) Sedimentation and OC Accumulation Rates
Published Regional Fluxes are Long-Term Estimates!

Burial - dominated by terrestrial soil OC

Mineralization - dominated by respiration of marine

Export - composed of soil OC
Theme II: Issue of timescales
Challenge in reconciling measurements at different timescales
Is the carbon sediment sink at steady state?

Example of Po River Delta core evolution and ultimate fate of Carbon in sediment sink (Tesi et al., submitted)

100-year flood in Po River
Produced a 24-cm thick deposit that was studied over a 10 year period
Physical processes and biological activity changed texture and carbon content/composition of surface horizons of deposit

⇒ Mixing, winnowing, degradation

Microbial biological activity changed the carbon content/composition of deeper horizons ⇒ Preferential degradation of labile materials
Theme II: Issue of timescales
Role of events at all timescales (days to decades/centuries) in Carbon Burial
Examples: wind-driven upwelling, storms, floods, earthquakes
*The carbon sediment sink is not at steady state at these scales!*
Example of Hurricanes (Katrina/Rita accumulations)
Goni et al., 2007; Dail et al., 2007; Corbett et al. unpub.
Effect of hurricanes were order of magnitude higher than ‘steady-state’

Storm Deposit Thicknesses

Rates of Storm-induced Accumulations

Table 1. Estimates of total mass accumulation of sediment, organic carbon and nitrogen on the seabed due to the combined Rita and Katrina events in contrast to annual inputs by rivers and regional primary production.

<table>
<thead>
<tr>
<th></th>
<th>Sediment</th>
<th>Organic Carbon</th>
<th>Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rita/Katrina Accumulations (g)</strong></td>
<td>$1.16 \times 10^{15} \pm 1.56 \times 10^{14}$</td>
<td>$1.36 \times 10^{13} \pm 2.46 \times 10^{12}$</td>
<td>$1.56 \times 10^{12} \pm 2.5 \times 10^{11}$</td>
</tr>
<tr>
<td><strong>Annual Inputs (g/y)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined Mississippi/Atchafalaya Rivers</td>
<td>$2.16 \times 10^{14}$</td>
<td>$3.62 \times 10^2$</td>
<td>$3.96 \times 10^{11}$</td>
</tr>
<tr>
<td>Regional Net Primary Production</td>
<td></td>
<td>$1.05 \times 10^{13} \pm 3.82 \times 10^{12}$</td>
<td>$1.74 \times 10^{12} \pm 6.36 \times 10^{11}$</td>
</tr>
<tr>
<td><strong>Non-Hurricane Accumulations (g/y)</strong></td>
<td>$1.18 \times 10^{14}$</td>
<td>$1.17 \times 10^2$</td>
<td>$1.40 \times 10^{11}$</td>
</tr>
</tbody>
</table>

Seabed accumulation rates account for the porosity values measured in storm and non-storm deposits. Estimates of annual inputs (river discharge and primary productivity) and of non-hurricane accumulations are from Gordon and Goni, 2004.
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Theme III: Spatial heterogeneity
Carbon contents, compositions and burial rates not evenly distributed along/across margins

Examples: Papua New Guinea

NW Gulf of Papua
High River discharge
Mesotidal
Variable wave regime
Active clinoform
Terrigenous & Marine OC Accumulation Fluxes

Marine OC Fluxes

Terrigenous OC Fluxes

[Graph showing marine and terrigenous OC accumulation fluxes with specific percentages and contributions indicated on the graph.]
Theme III: Spatial heterogeneity
Importance of magnitude and composition of sediment and OM supply
-- Role of rivers in supplying fine sediments to enhance allochthonous and autochthonous OM accumulations. Umpqua shelf.

**Summer Conditions**
*Upwelling-Favorable*

- Equatorward Winds
- No River Input

**Winter Conditions**
*Downwelling-Favorable*

- Poleward Winds
- High Waves
- River Input
Sediment & Carbon Distributions

River Depocenter

Sediment Texture

Carbon Content

Grain Size (μm)

%OC

Sed. Rates:

3 – 5 mm/y

0.5 – 1.0 mm/y
Shape of Carbon Depocenter Regulated by:

Fluvial Inputs (High Terrigenous Character) AND
Physical processes (coherence between discharge and waves/currents)
Future Needs to Integrate Benthic Processes/Fluxes with rest of NACM Efforts

Observations at appropriate (i.e., multiple) temporal scales
Seasonal, event –scale measures of carbon sediment sink

Observations at appropriate (i.e. multiple) spatial scales
Integration of chemical and geological variability (i.e. sediment types, accumulation rates)

Model-Data Integration

Combine observations and models of sediment dynamics with observations and models of biogeochemical cycling

Integrate observations and models at different time scales
Upcale short-term observations to annual, multi-annual scales
Decipher the relationships between decadal scale sediment records with shorter time scale processes in the water column
Theme III: Spatial heterogeneity

Importance of O2 exposure time
Keil/Harnett

Challenges for estimating fluxes at whole-margin, continent-wide scales