Carbon Remineralization and Burial in the Coastal Margin: Linkages in the Anthropocene

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1853

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NSF

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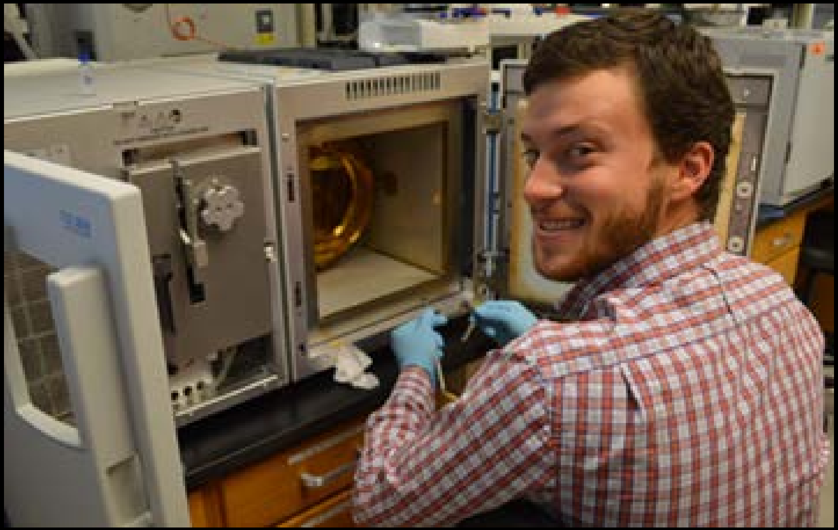
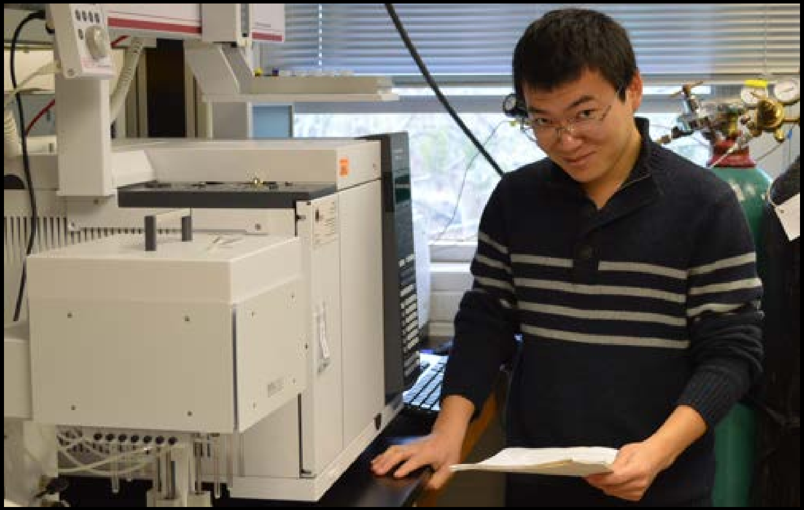
NSFC
National Natural Science
Foundation of China

U.S. DEPARTMENT OF
ENERGY

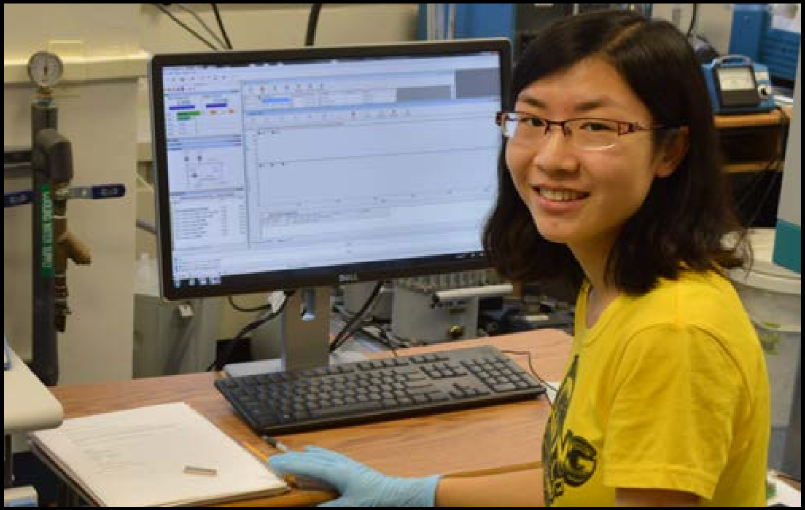
The Key Players



Michael Shields, Postdoc at UF



Xingqian Cui, Postdoc at MIT



Xiaowen Zhang, Postdoc at MIT

Jack Hutchings, Researcher, Washington University

Seminar Outline

1. "Hot Spots" and Controls of Organic Carbon Burial in Global Ocean

2. Organic Carbon Dynamics in Large River Deltas

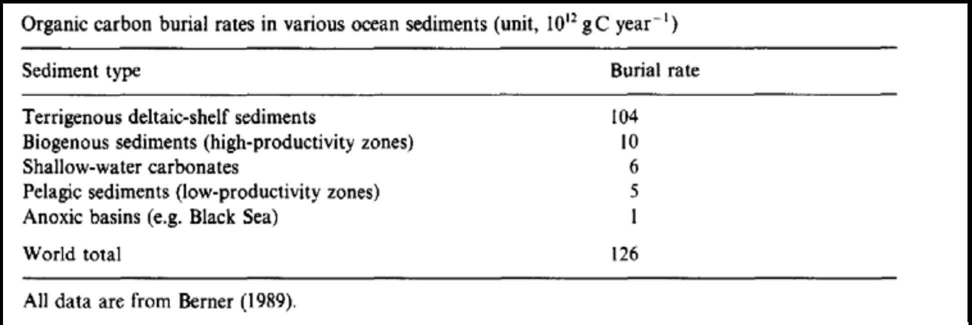
3. A "Kink" in the Aquatic Continuum

4. Organic Carbon Dynamics in Fjords

5. Carbon Sequestration on an Embryonic Delta and Coastal U.S. Wetlands

“Hot Spots” and Controls of Organic Carbon Burial in Global Ocean

Evolution of Global Ocean Carbon Burial



Organic carbon burial rates in various ocean sediments (unit, 10^{12} gC $year^{-1}$)

Sediment type	Burial rate
Terrigenous deltaic-shelf sediments	104
Biogenous sediments (high-productivity zones)	10
Shallow-water carbonates	6
Pelagic sediments (low-productivity zones)	5
Anoxic basins (e.g. Black Sea)	1
World total	126

All data are from Berner (1989).

Hedges (1992) *Mar. Chem.*

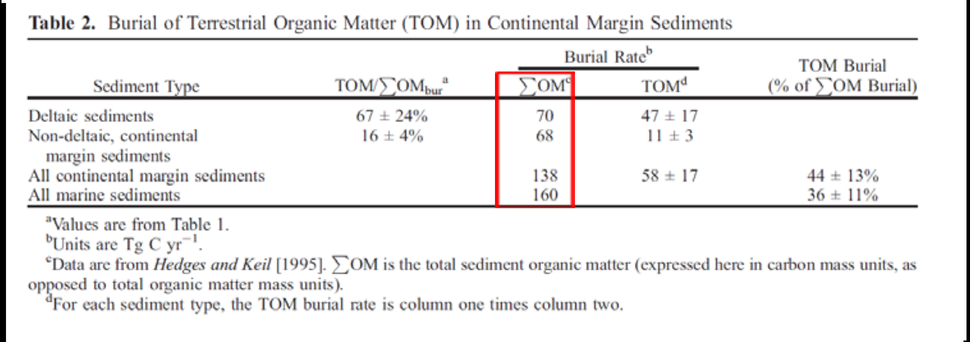


Table 2. Burial of Terrestrial Organic Matter (TOM) in Continental Margin Sediments

Sediment Type	$TOM/\sum OM_{bur}$[a]	Burial Rate[b] $\sum OM$[c]	TOM[d]	TOM Burial (% of $\sum$OM Burial)
Deltaic sediments	67 ± 24%	70	47 ± 17	
Non-deltaic, continental margin sediments	16 ± 4%	68	11 ± 3	
All continental margin sediments		138	58 ± 17	44 ± 13%
All marine sediments		160		36 ± 11%

[a] Values are from Table 1.
[b] Units are Tg C yr^{-1}.
[c] Data are from *Hedges and Keil* [1995]. $\sum$OM is the total sediment organic matter (expressed here in carbon mass units, as opposed to total organic matter mass units).
[d] For each sediment type, the TOM burial rate is column one times column two.

Burdige (2005) *Global Biogeochem. Cycl.*

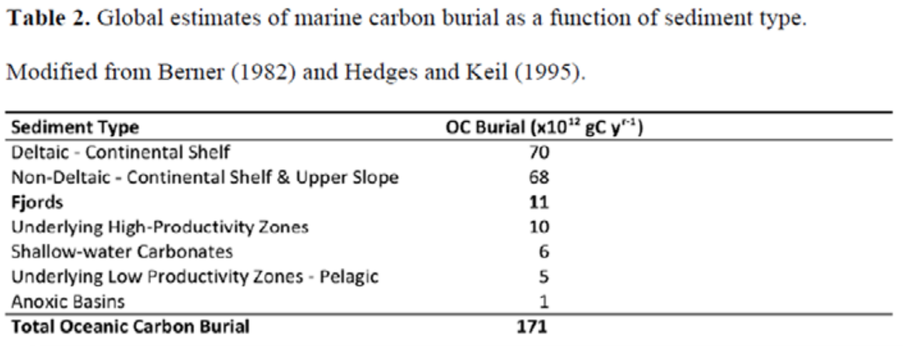
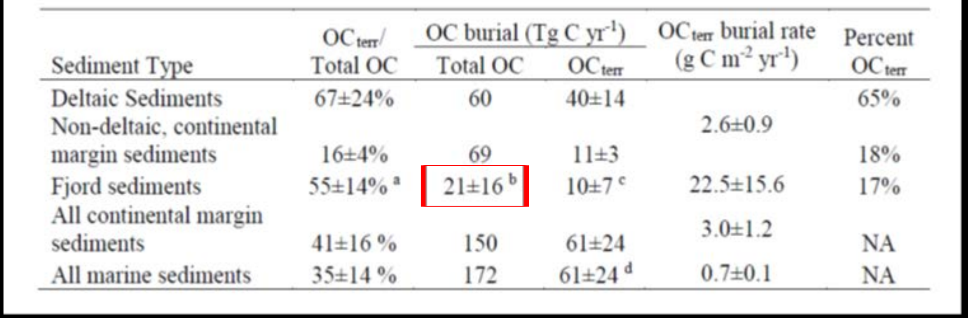


Table 2. Global estimates of marine carbon burial as a function of sediment type.

Modified from Berner (1982) and Hedges and Keil (1995).

Sediment Type	OC Burial (x10^{12} gC y^{r-1})
Deltaic - Continental Shelf	70
Non-Deltaic - Continental Shelf & Upper Slope	68
Fjords	**11**
Underlying High-Productivity Zones	10
Shallow-water Carbonates	6
Underlying Low Productivity Zones - Pelagic	5
Anoxic Basins	1
Total Oceanic Carbon Burial	**171**

Smith, Bianchi et al. (2015) *Nat. Geosci.*



Sediment Type	OC_{terr}/ Total OC	OC burial (Tg C yr^{-1}) Total OC	OC_{terr}	OC_{terr} burial rate (g C m^{-2} yr^{-1})	Percent OC_{terr}
Deltaic Sediments	67±24%	60	40±14	2.6±0.9	65%
Non-deltaic, continental margin sediments	16±4%	69	11±3		18%
Fjord sediments	55±14% [a]	21±16 [b]	10±7 [c]	22.5±15.6	17%
All continental margin sediments	41±16 %	150	61±24	3.0±1.2	NA
All marine sediments	35±14 %	172	61±24 [d]	0.7±0.1	NA

Cui, Bianchi et al (2016) *Earth. Planet. Sci. Lett.*

Burial of Sedimentary Organic Carbon (OC)

Most OC (ca. 86%) is preserved in continental margin sediments (Berner, 1982; Hedges, 1992; Burdige, 2005, 2006).

Why?

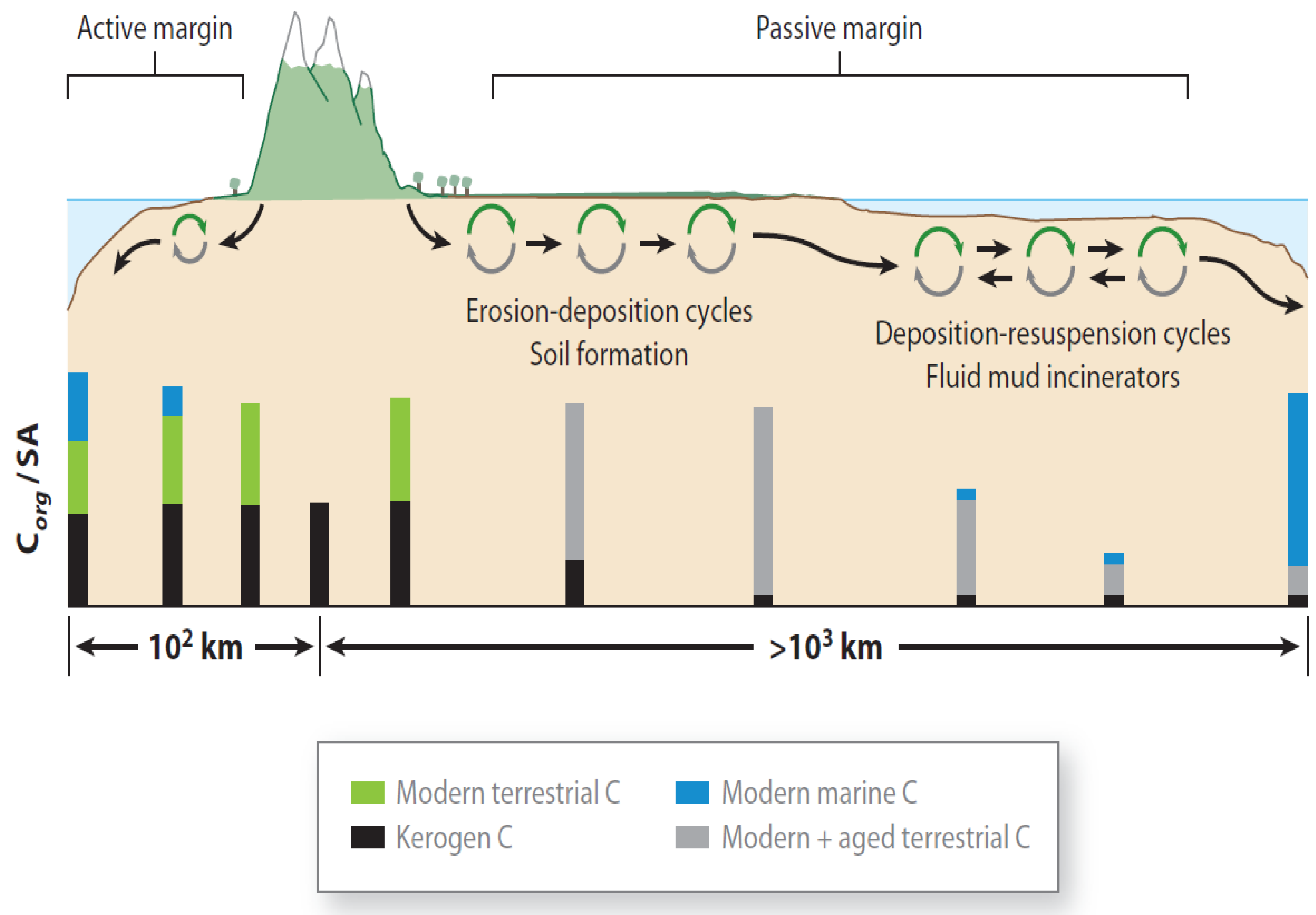
1. Sedimentation rate, or rate of burial is an important factor
2. Redox conditions/oxygen exposure can be a factor
3. Surface Area/mineralogy/aggregates appear to be very important
4. Selective preservation based on biochemical properties
5. Geopolymerization – abiotic linkages
6. Co-precipitation and sorption to reactive Fe

The “mechanisms” of carbon preservation are still not understood. Many relationships between %OC, sedimentation rate, surface area, oxygen, have been shown, but we do not have a clear mechanistic explanation for why these relationships are observed.

The Aquatic Continuum

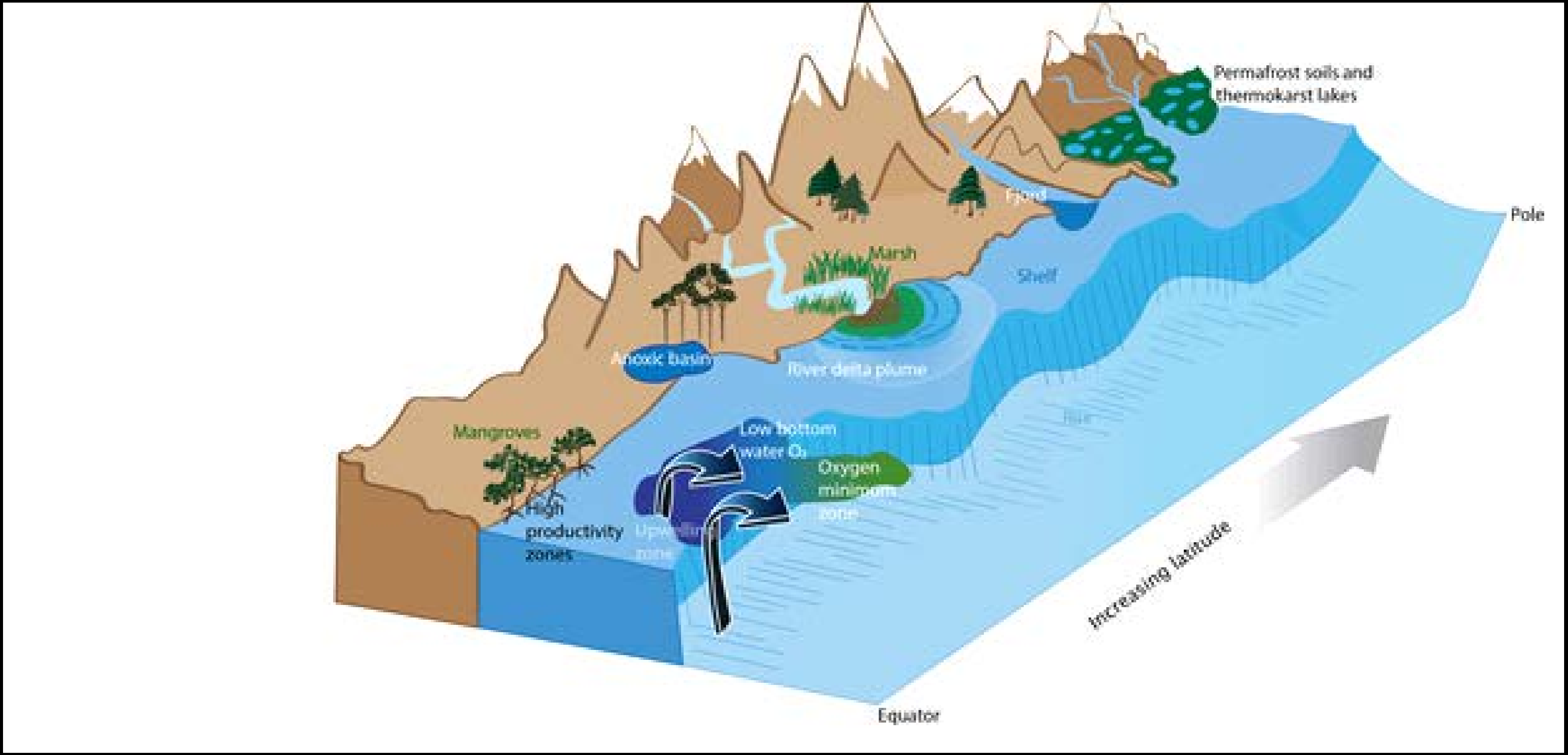
Ward, Bianchi, et al. (2017) *Front. Mar. Sci.*

Passive and Active Margin Drivers of OC Burial and Transport: Source-to-Sink



Blair and Aller (2012) *Ann. Rev. Mar. Sci.*

“Hot-Spots” of Carbon Burial in the Continuum at the Coastal Margin



Bianchi et al. (2016) *Ann. Rev. Earth Plant. Sci.*

Large-River Deltaic-Estuaries

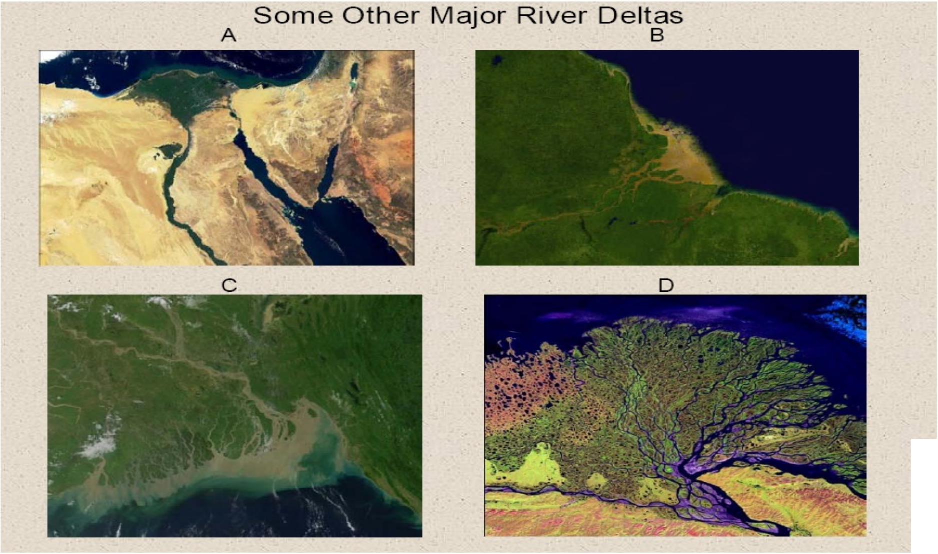


Figure 1. Some other major deltas of the world: (A) Nile; (B) Amazon; (C) Ganges-Brahmaputra; (D) Lena.

Intertidal and Sub-tidal Habitats for OC Burial

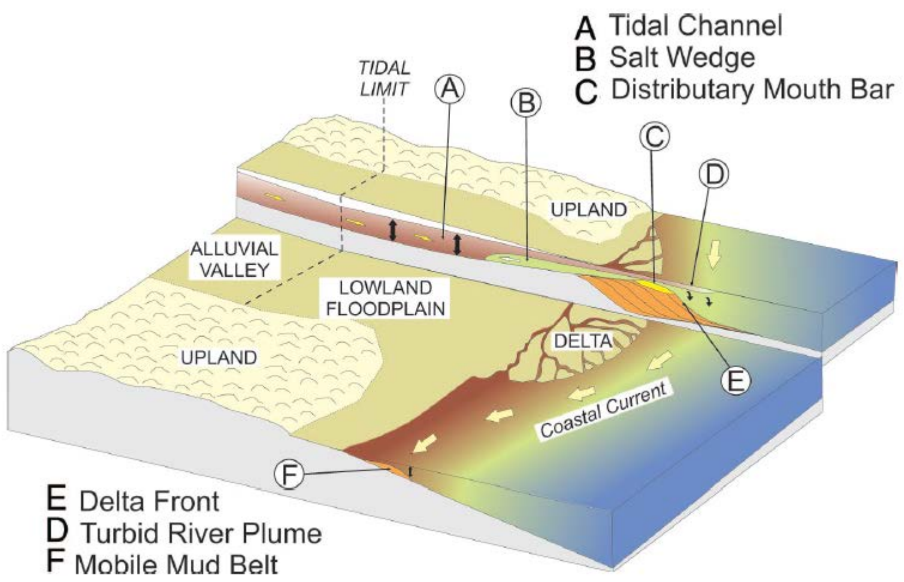
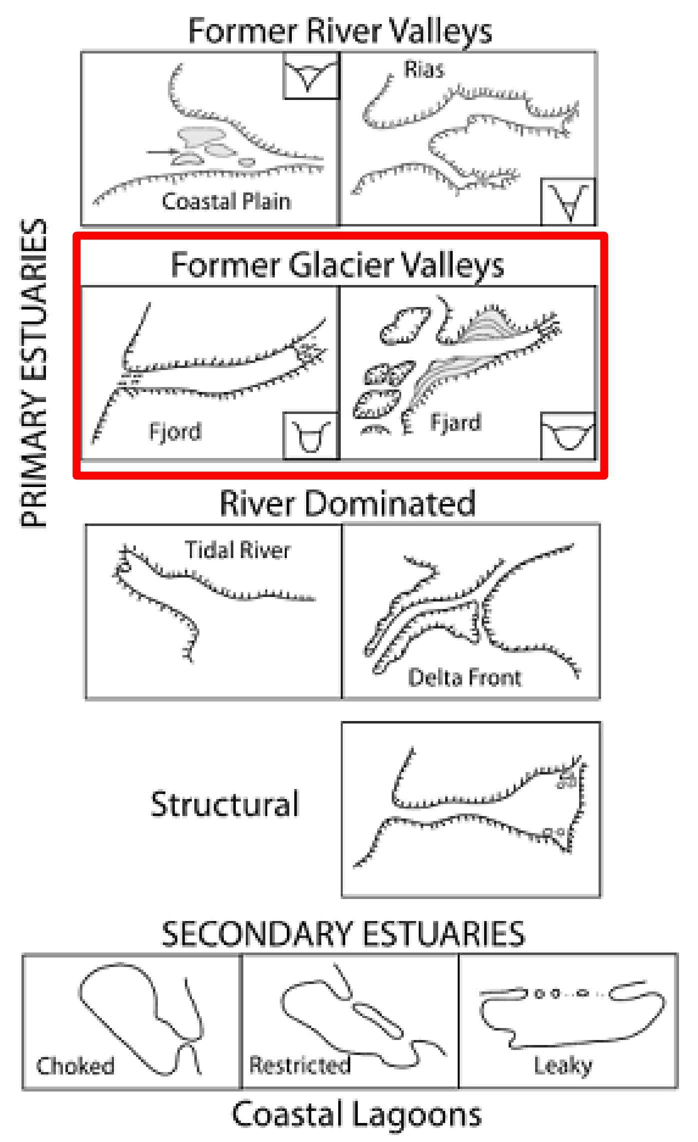
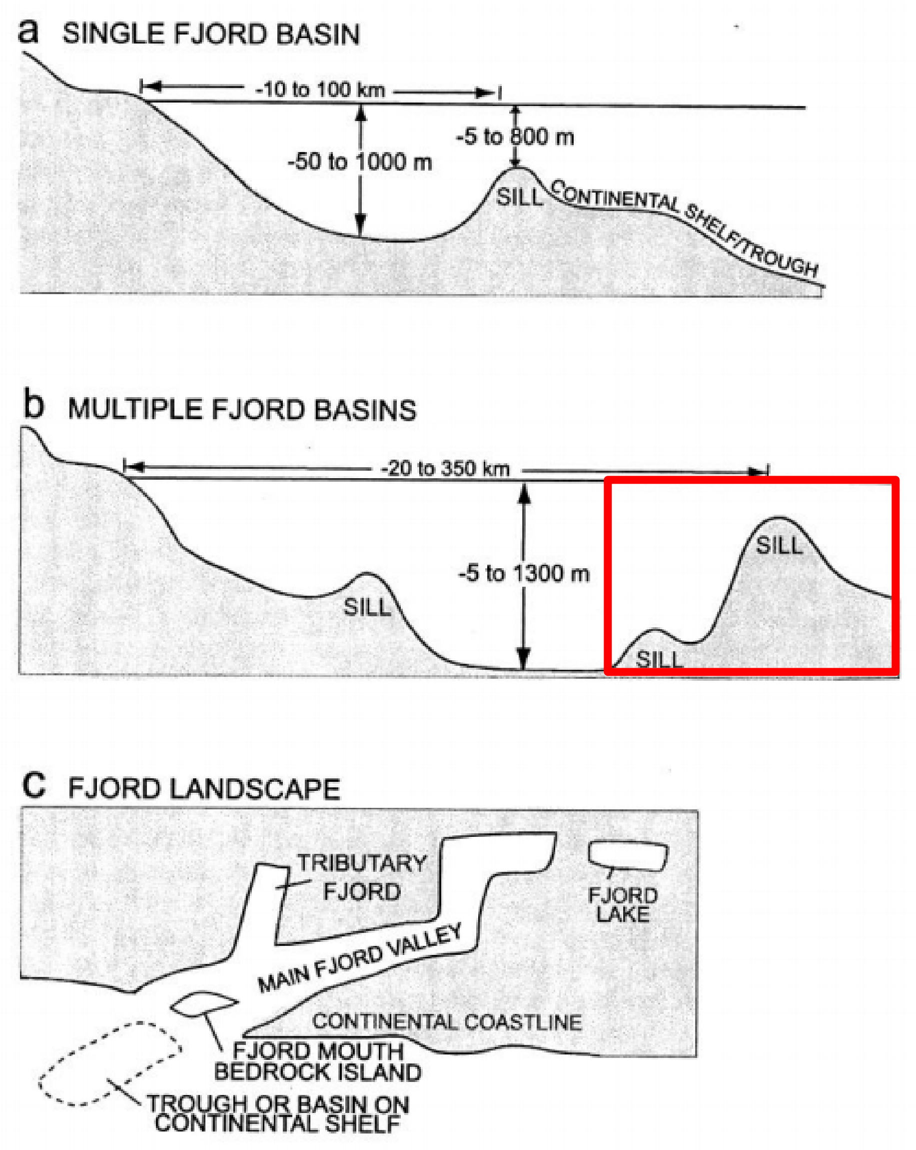


Fig. 2. Regional geomorphogical boundaries and associated sedimentary deposits within an LDE.

Bianchi and Allison (2009) *Proc. Nat. Acad. Sci.*

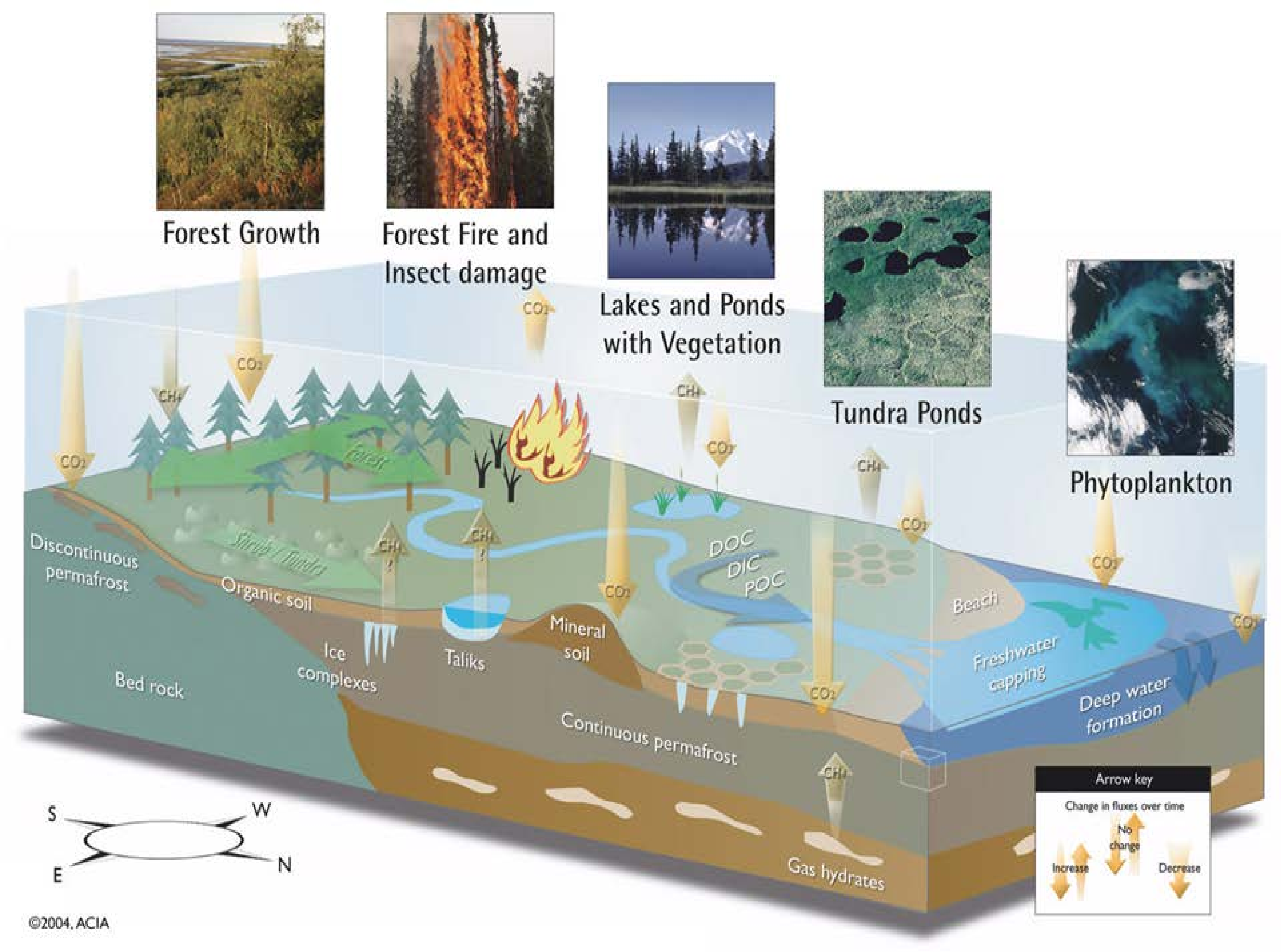
Fjords





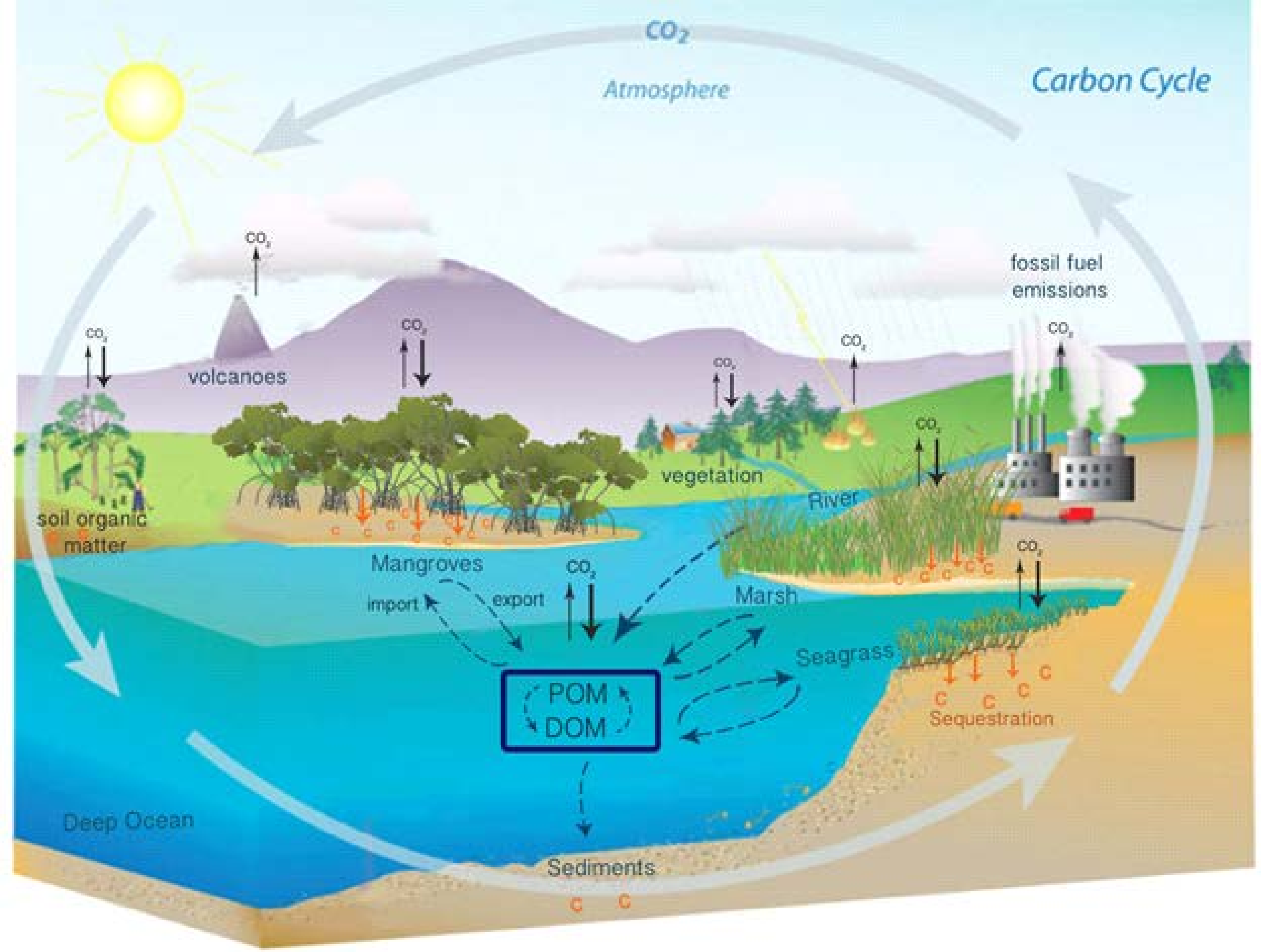
Bianchi (2007) *Biogeochemistry of Estuaries, Oxford Univ. Press*

Different “Rules”in the Arctic Aquatic Continuum



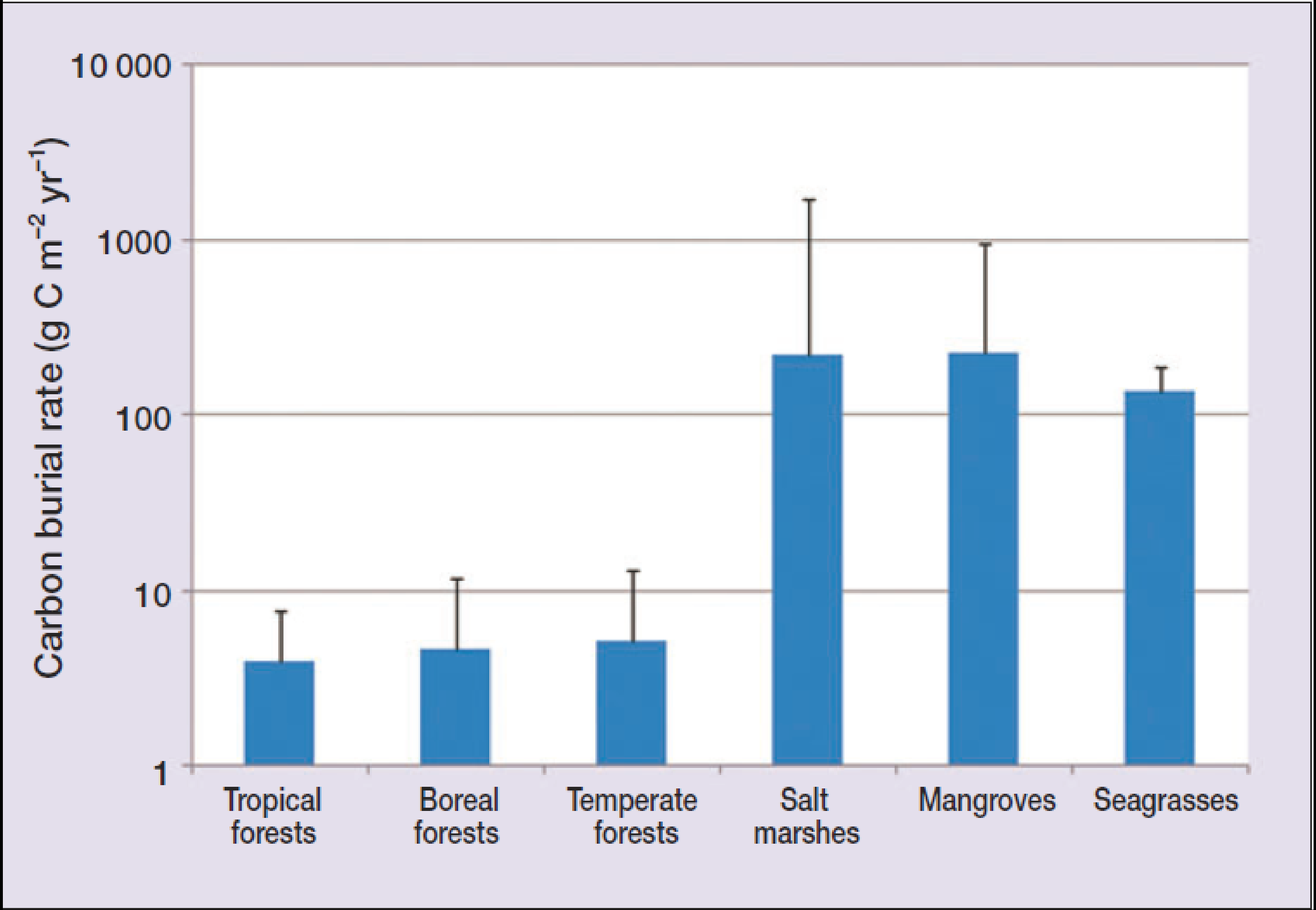
©2004, ACIA

“Hot Spots” for Carbon Sequestration at the Land-Ocean Boundary of the Aquatic Continuum



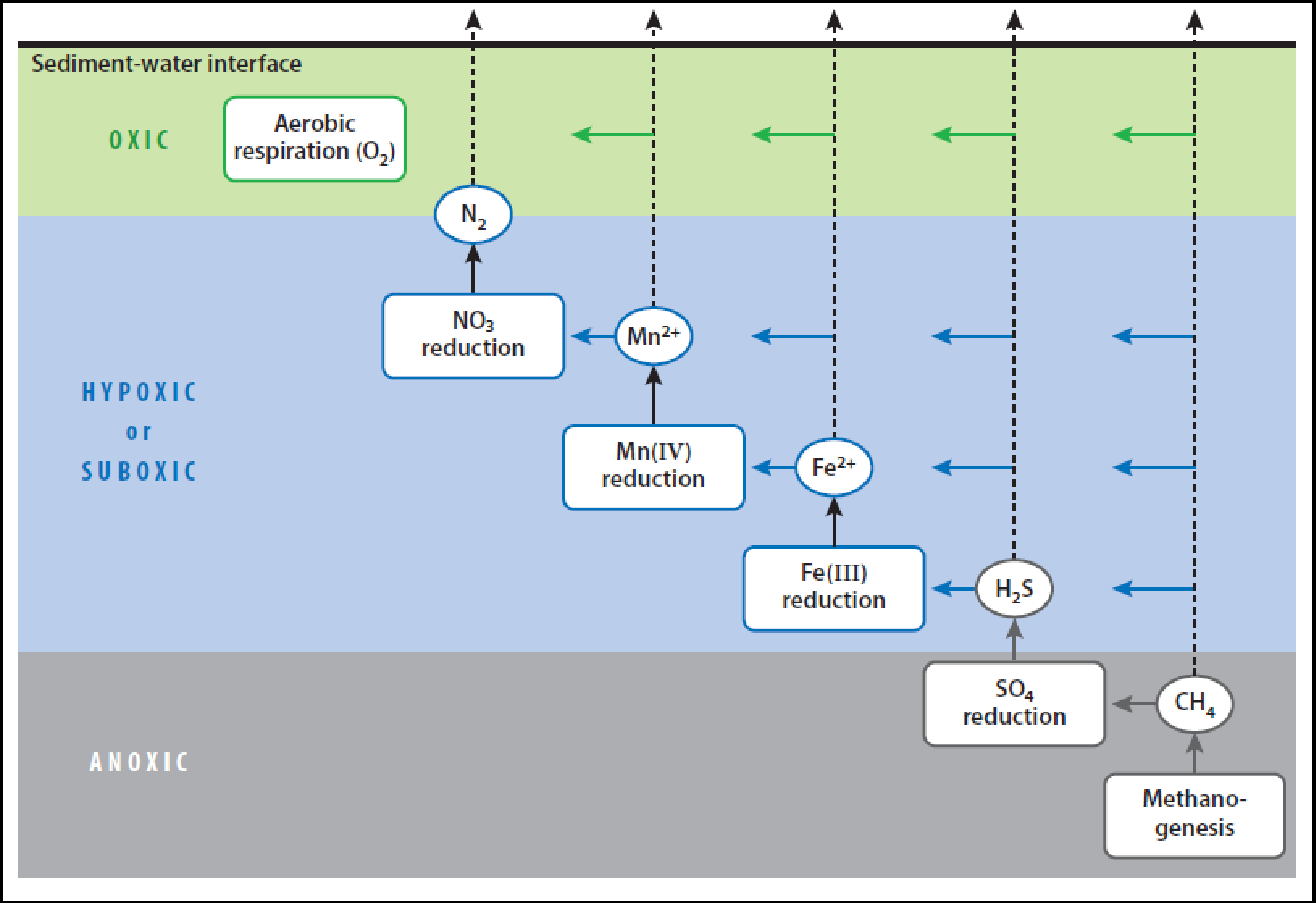
Bianchi et al., 2018 (In: Wyndam et al. 2018 A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice, and Policy (CRC Press)

Carbon Sequestration in Terrestrial versus Blue Carbon Systems



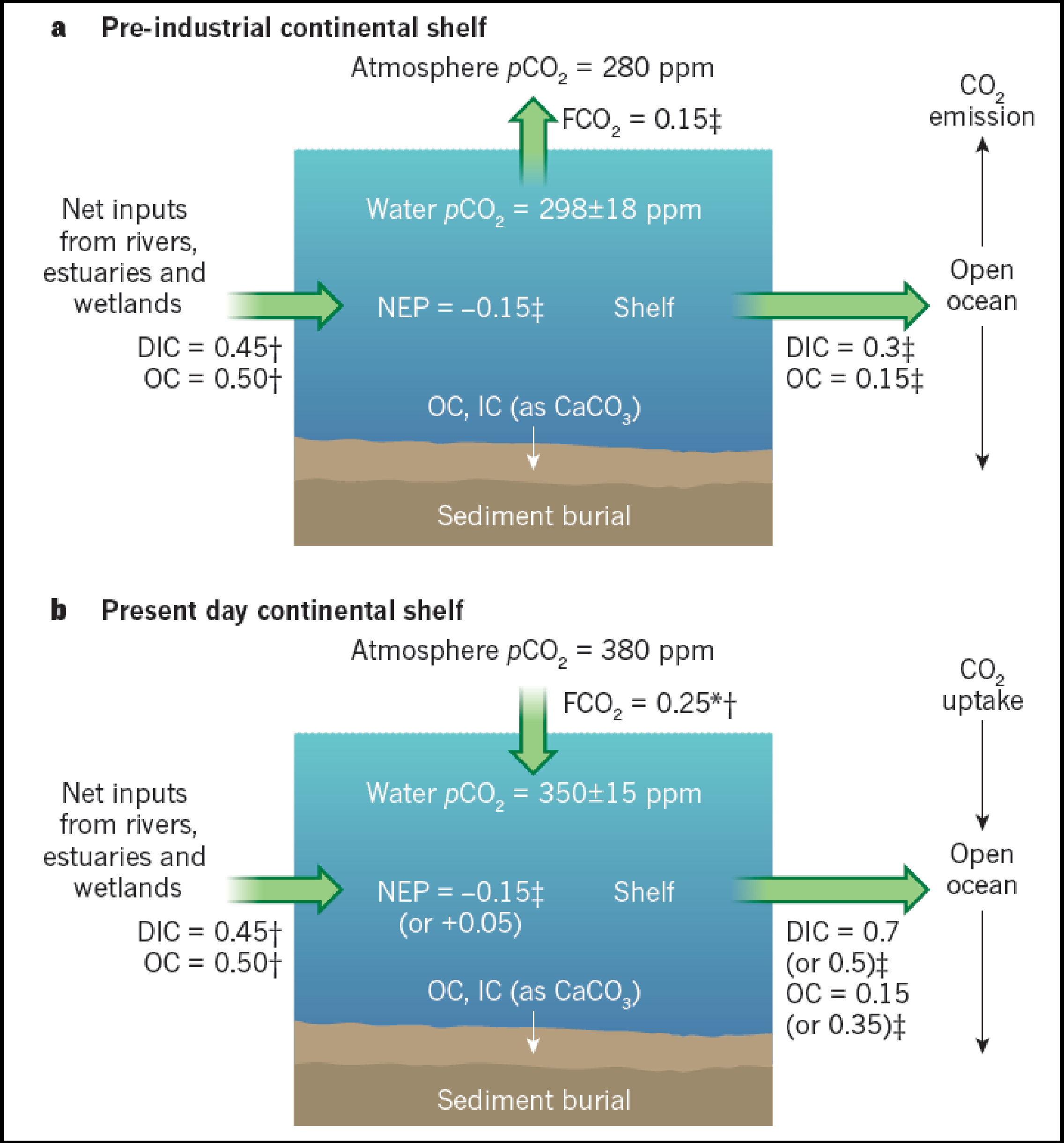
Mcleod et al. (2011) *Front. Ecol*

Redox Effects



Bianchi et al. *Ann. Rev. Earth Planet Sci.* (2016)

Changes in Coastal Carbon Loading/Sequestration

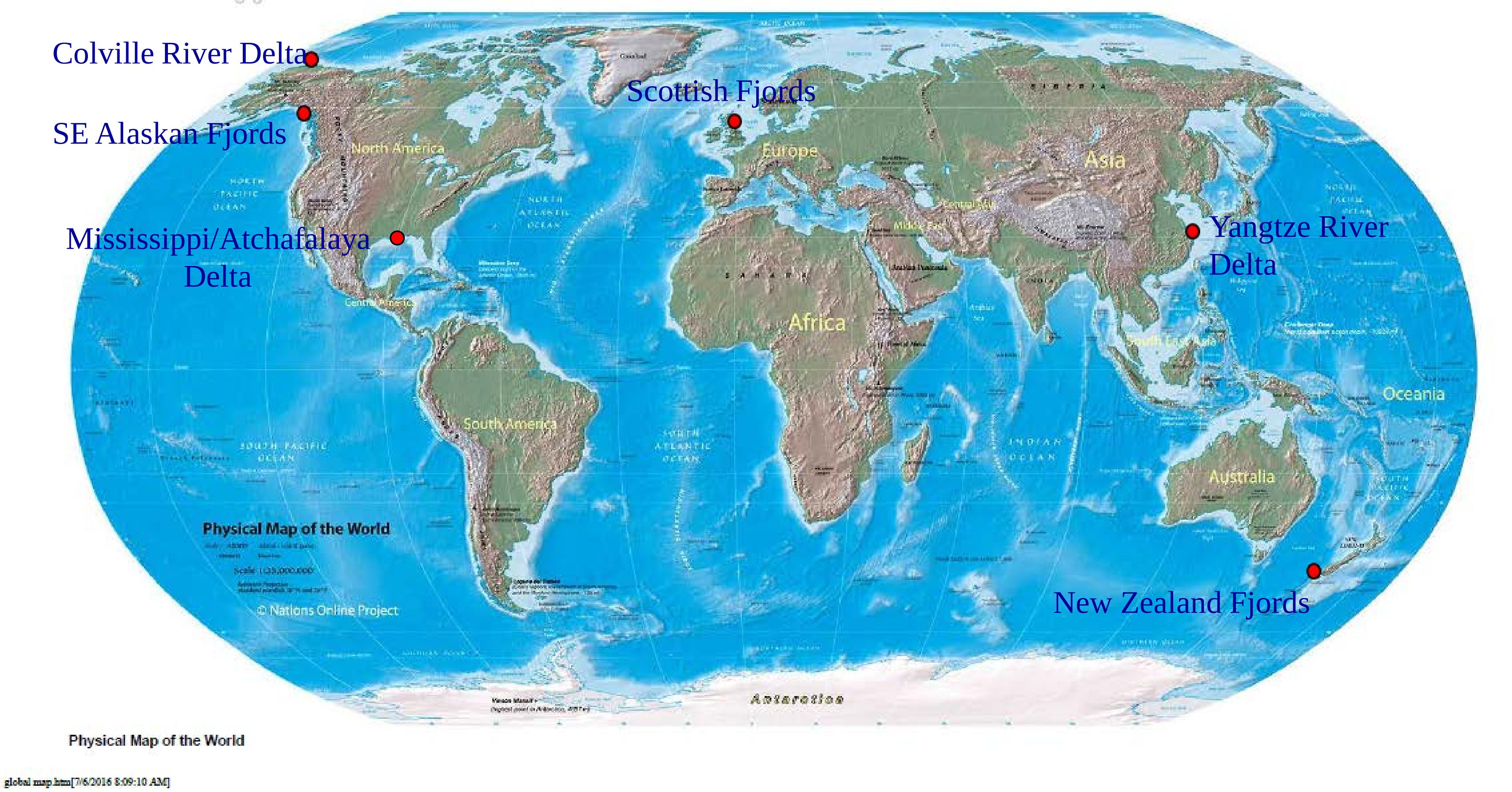


Coastal ocean has largely been a net sink for atmospheric carbon dioxide during post-industrial times.

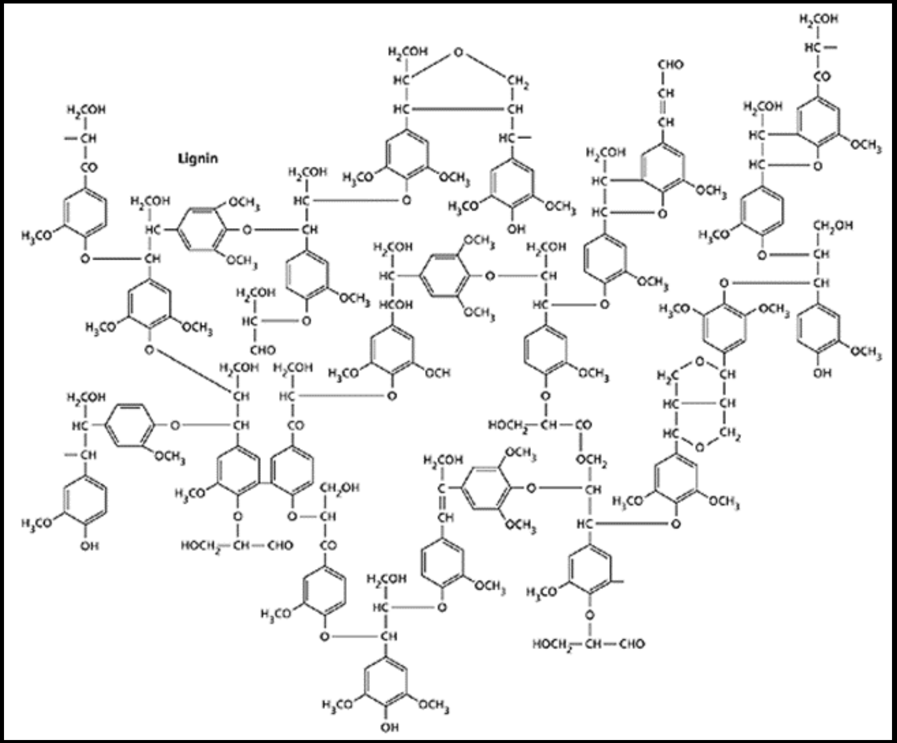
All carbon fluxes including NEP have units of Pg C yr−1.

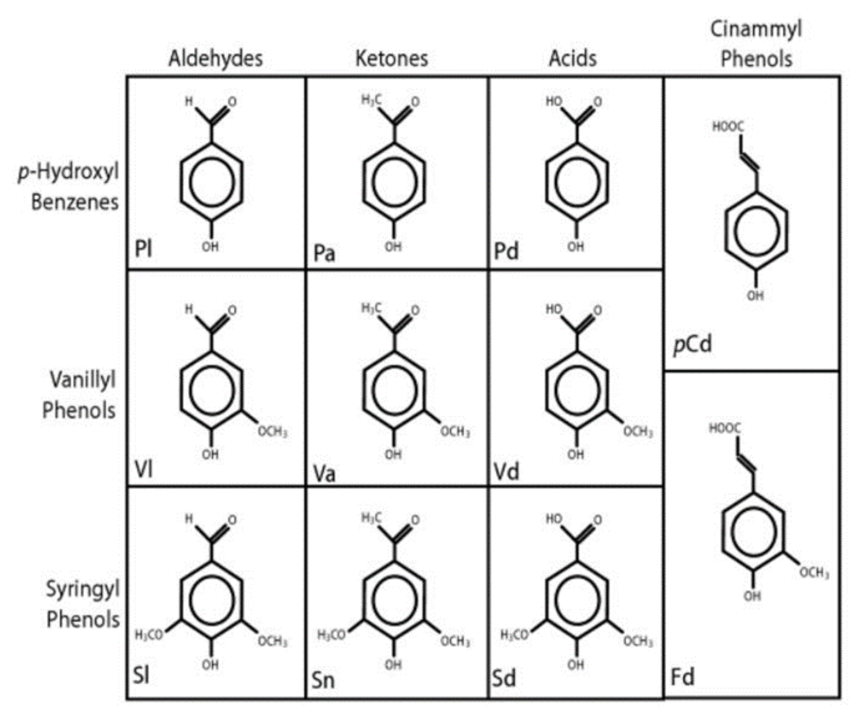
Bauer, Bianchi, et al. *Nature* (2013)

Coastal Study Sites



Lignin as a Chemical Biomarker of Vascular Plants





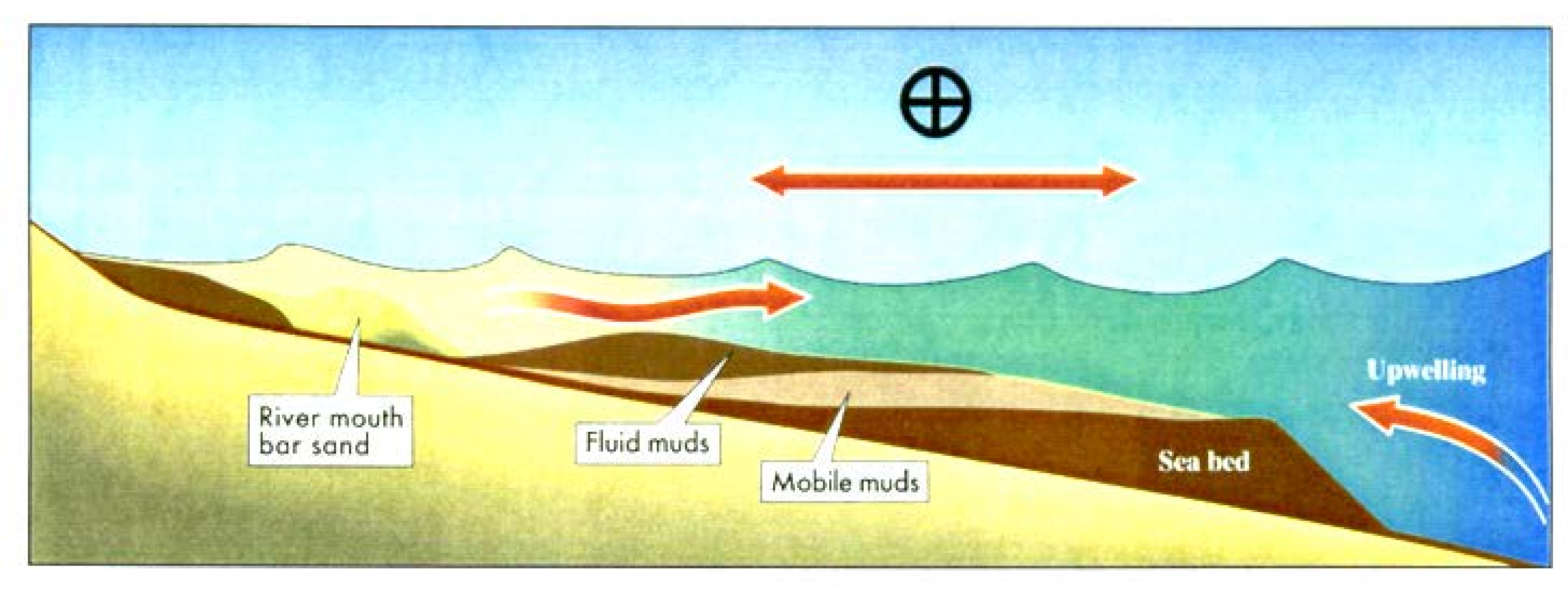
Hedges and Ertel (1982) *Anal. Chem.*

Λ8 (mg/100 mg OC)

Bianchi and Canuel (2011) *Chemical Biomarkers in Aquatic Ecosystems*, Princeton Univ. Press

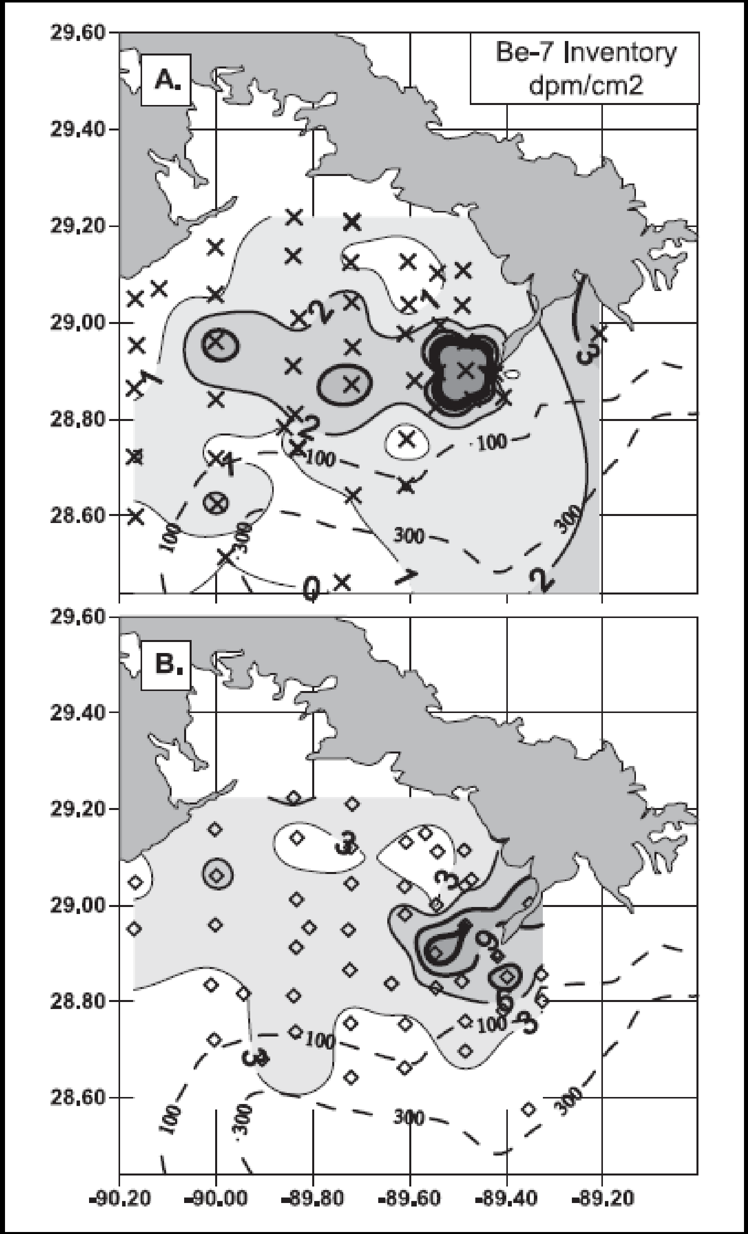
Organic Carbon Dynamics in Large River Deltas

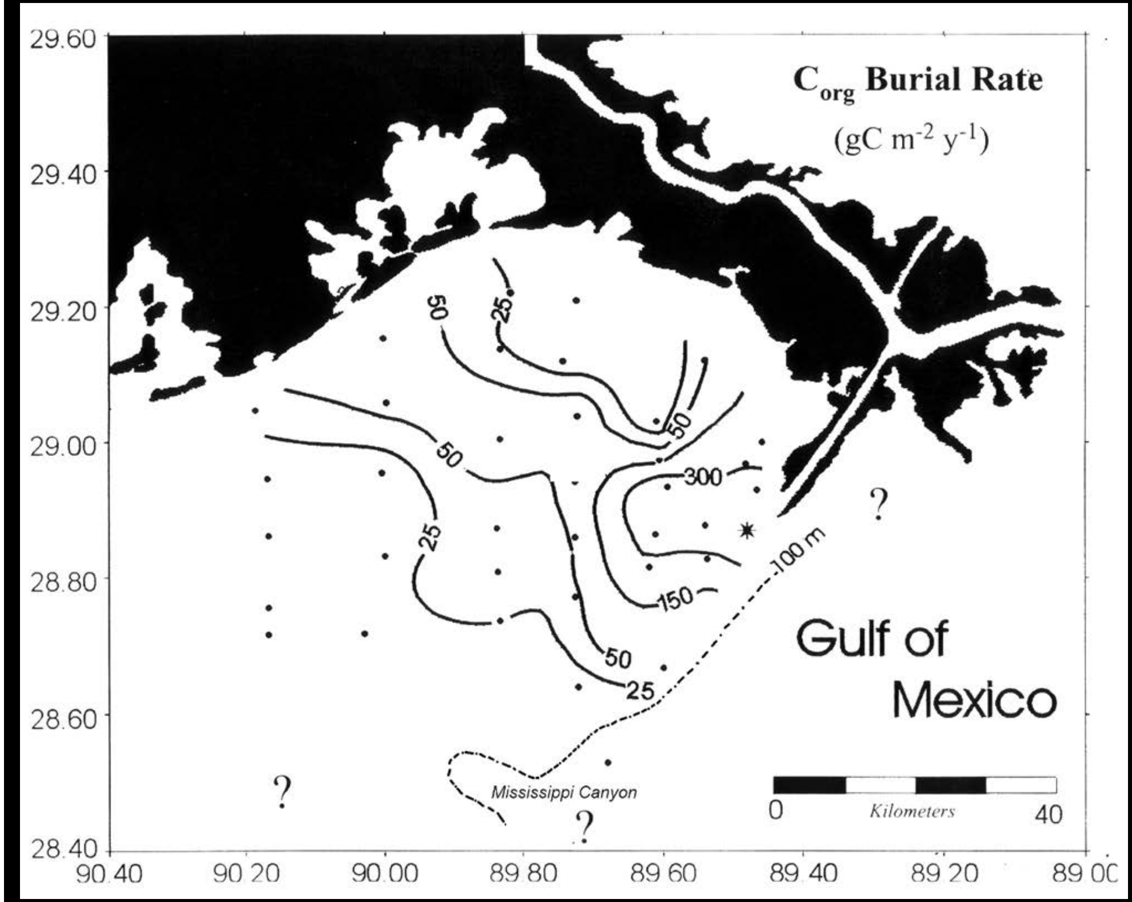
Deltaic and Fluid/Mobile Muds: Agents of Rapid Transport and OC Decay



McKee, Bianchi, et al. (2004) *Cont. Shelf Res.*

Spatial Variability of Surface Depositional Processes

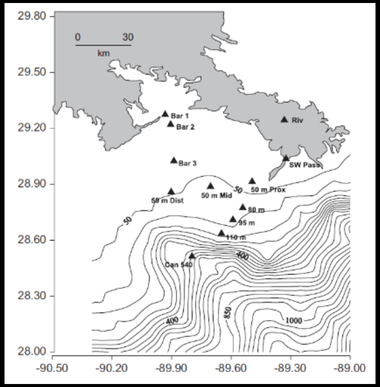




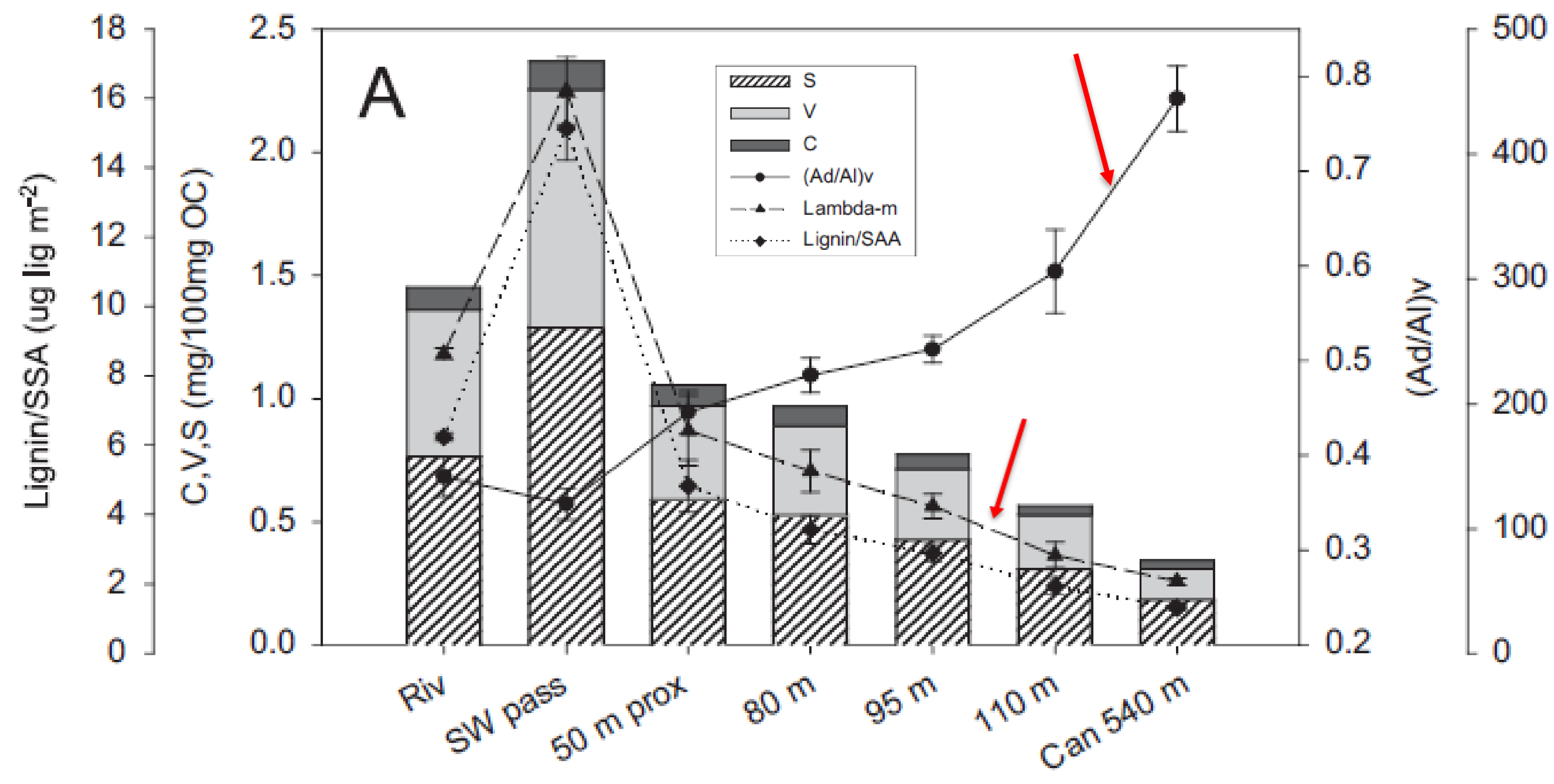
Seasonal movement of mobile muds as related to river discharge, A – rising discharge; B. falling discharge

Corbett et al. (2004) *Mar. Geol.*

Transport and Decay of Lignin

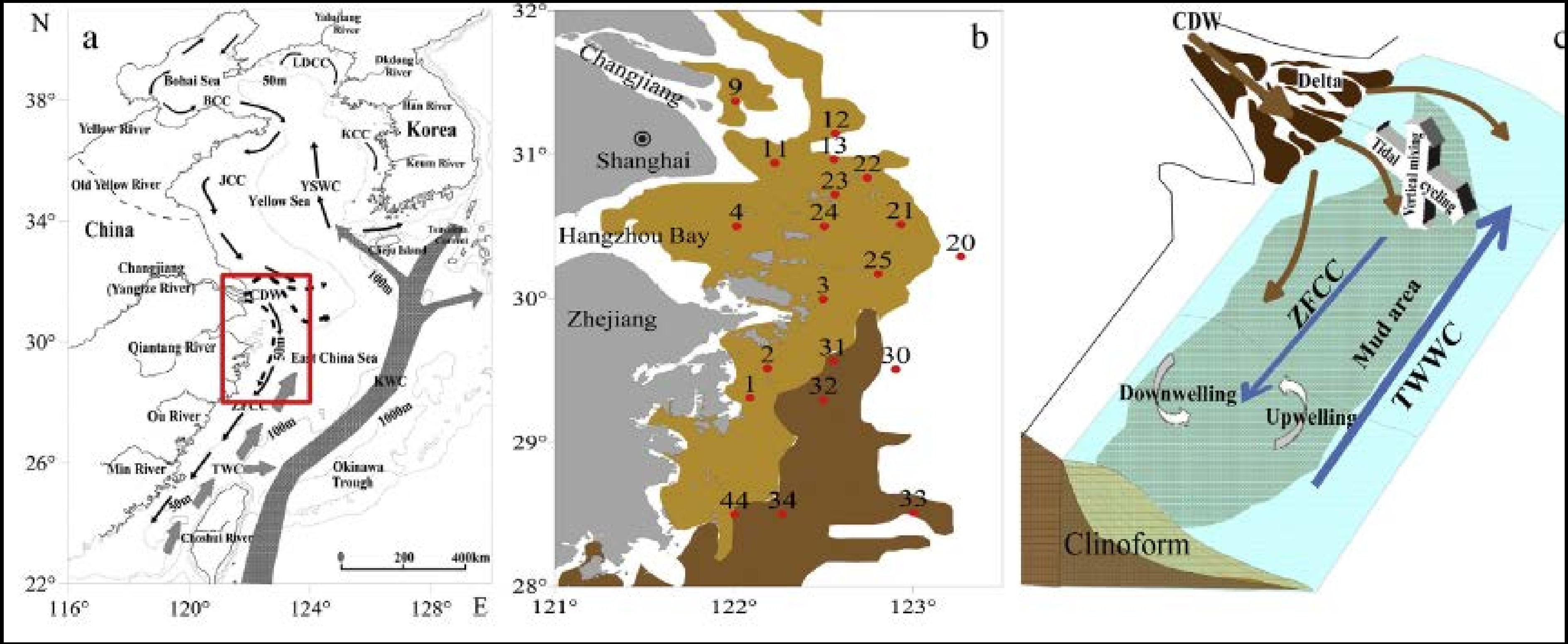


Lignin decreases across-shelf due in part to decomposition as evidenced by higher Ad/Al ratios, some loss may be due to transformation into other substances (e.g., carboxylic-rich alicyclic molecules [CRAM], personal comm. P. Hatcher).



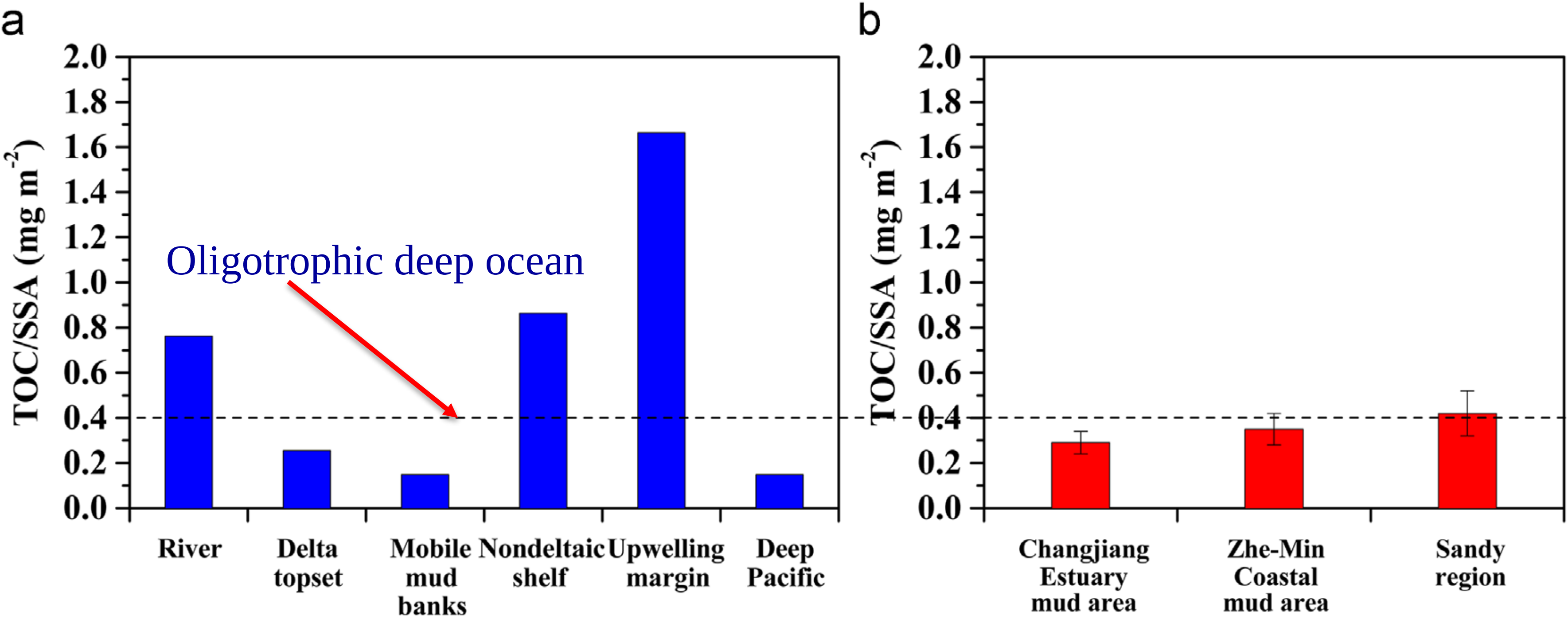
Sampere, Bianchi et al. (2008) *Cont. Shelf Res.*

Physical Drivers of Hydrodynamic Sorting in the Yangtze (Changjiang) River Delta Region



Li, Bianchi et al. (2014) *J. Mar. Syst. – modified from Liu et al. (2007) Geomorphology*

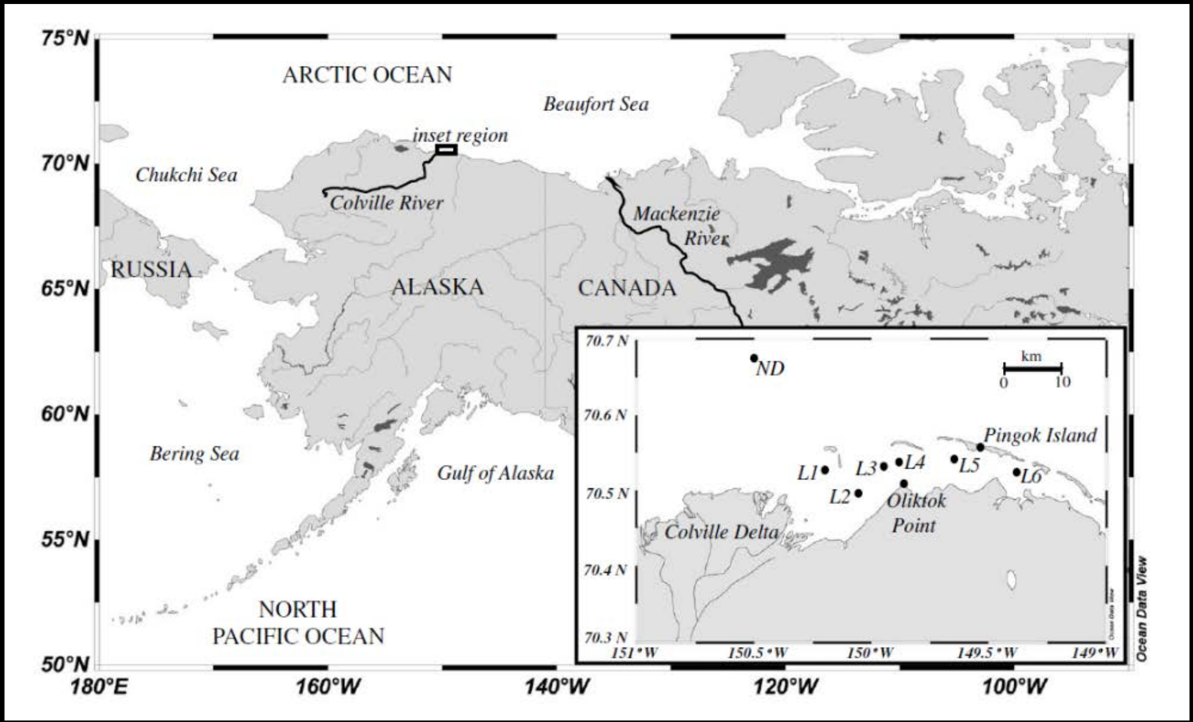
“Burn-Down” of OC in Mobile-Muds in Large-River Deltas



Dashed line of ≤0.4 represents values commonly found in oligotrophic open ocean sediments (e.g., highly degraded OC)

Collective data from: Aller (1998), *Mar. Chem.*; Aller and Blair (2004); Aller and Blair (2006) *GCA*; Aller and Blair (2006) *Cont. Shelf Res.*

Yao, Bianchi et al. (2014) *Cont. Shelf Res.*



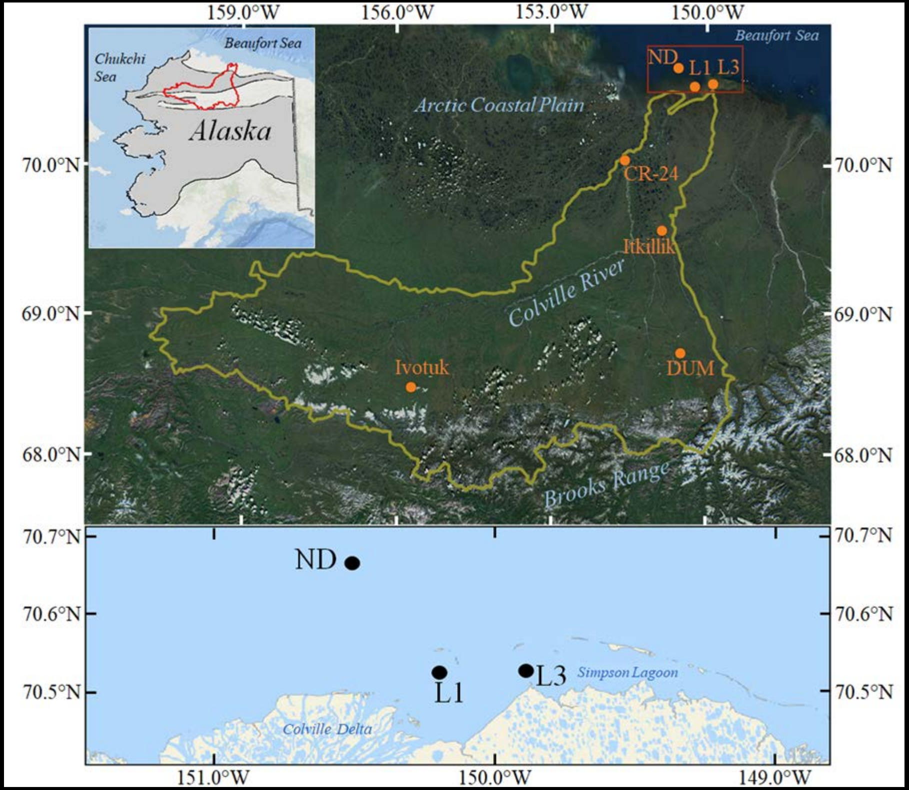
The Colville River is the largest river in North America that exclusively drains high-Arctic continuous-permafrost tundra

Deltaic POC sources from a variety of areas, including the Colville River, the Mackenzie River, direct coastal erosion (high in peat), aquatic (marine and freshwater, pelagic and benthic) algal production and **yedoma.**

Yedoma is an organic-rich (about 2% carbon by mass) Pleistocene-age permafrost with ice content of 50–90% by volume. Also, rich in "old" fatty acids and low in lignin-phenols (Vonk et al., 2010; Feng et al., 2013).

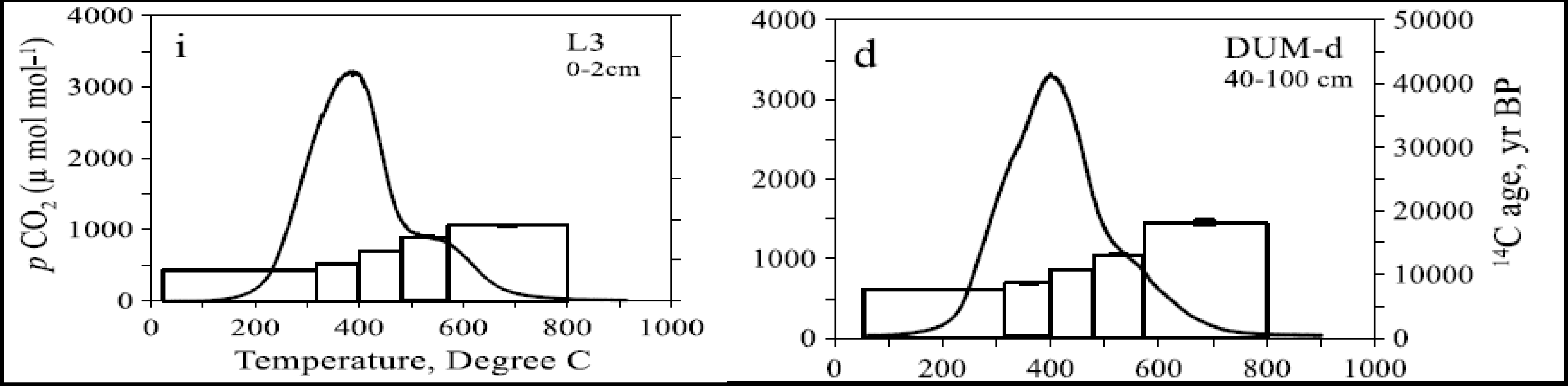
Schreiner, Bianchi, et al. (2013) *J. Geophys. Res. Biogeo.*

OC Permafrost Transport to Coast



Ramped pyrolysis-oxidation (RPO) radiocarbon analysis

Thermographs (black lines, left y axis) and C-14 age distribution of CO_2 splits (bars, right y axis).



Zhang, Bianchi et al. (2017) *Geophys. Res. Lett.*

Permafrost/Yedoma-Derived POC Transport to the Coast

Yedoma in the Arctic

Fig. 6. Block fall of the 35-m-high Itkillik River bluff, 16 August 2007, 5:14 a.m.

Zhang, Bianchi et al. (2017) *Geophys. Res. Lett.*

Old before your time…

So, as the rules continue to change in the Anthropocene, we can add yet another twist in this ever-changing epoch where a gastrotrich that lives for 3 days can be thousands of years old when it dies.

Guillemette, Bianchi, et al. (2017) *Limnol. Oceanogr.*

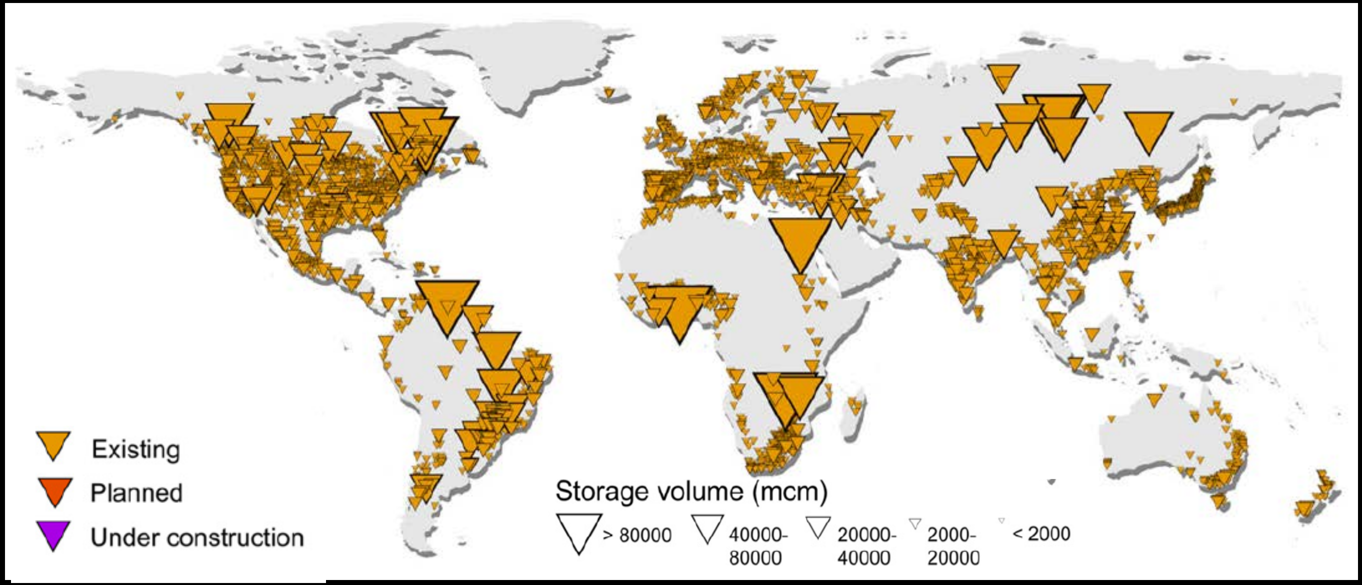
A “Kink” in the Aquatic Continuum

Changes in the Hinterland

In recent years , there has been an astonishing increase in the retention of water by rivers, estimated to be 600 to 700%, which has tripled the time is takes for a water molecule to be transported from land to sea.

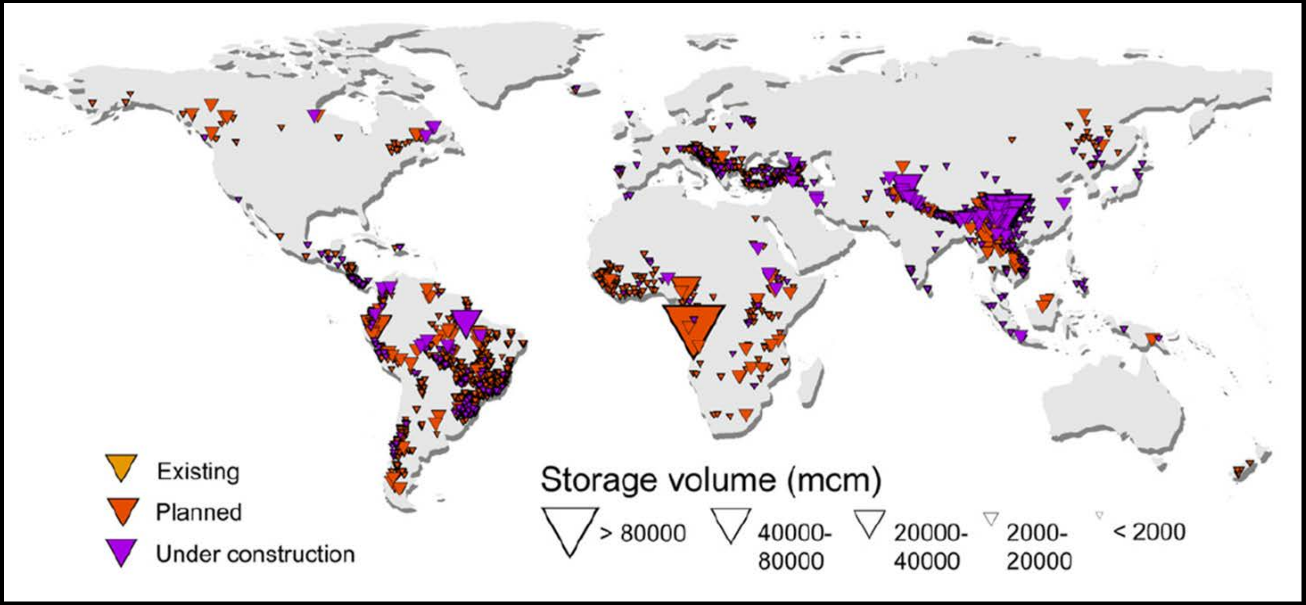
Vörösmarty et al . (2009) *Bull. At. Sci.*

The Damn Dams



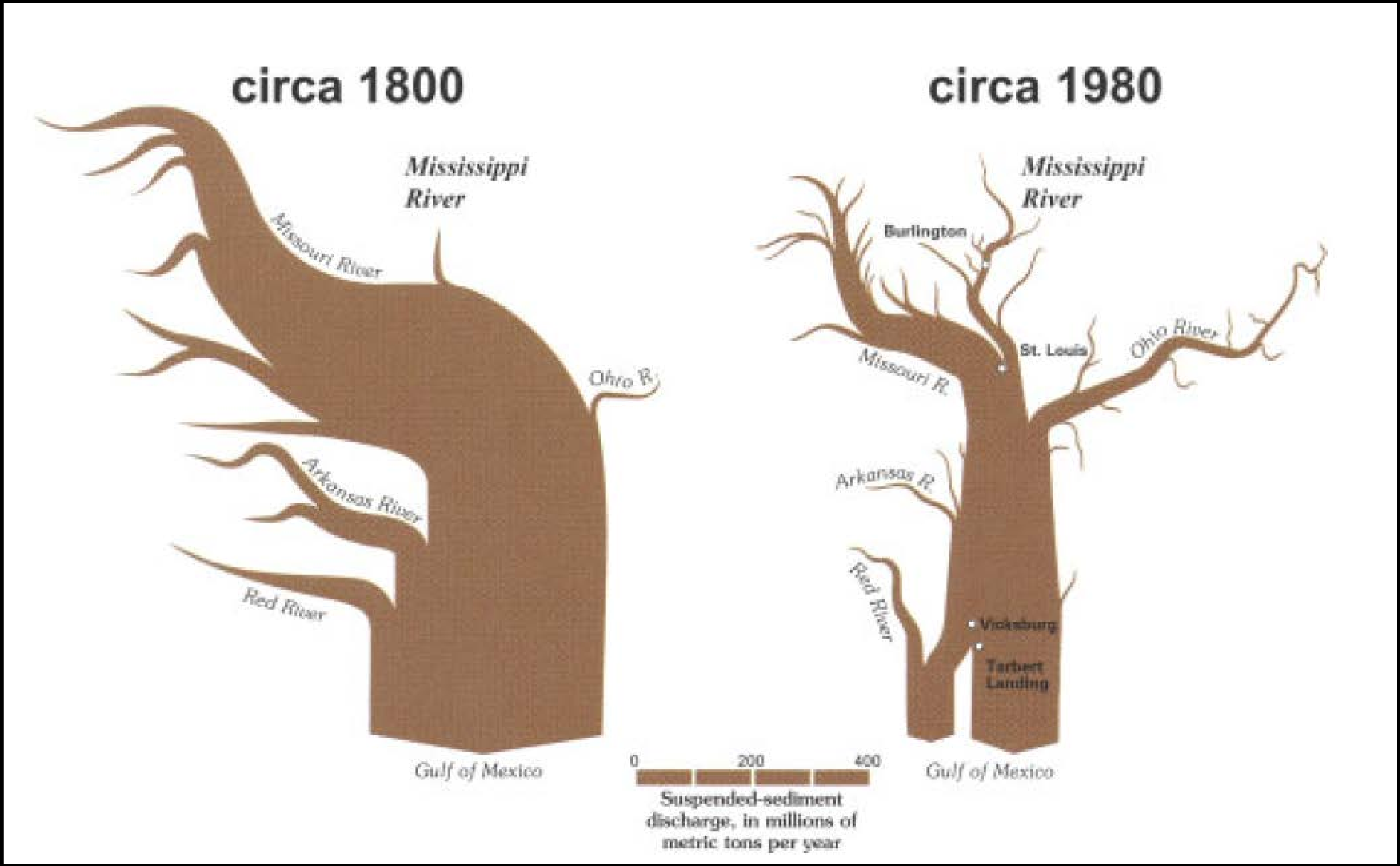
Existing Dams in the World

Dams Under Construction or Planned



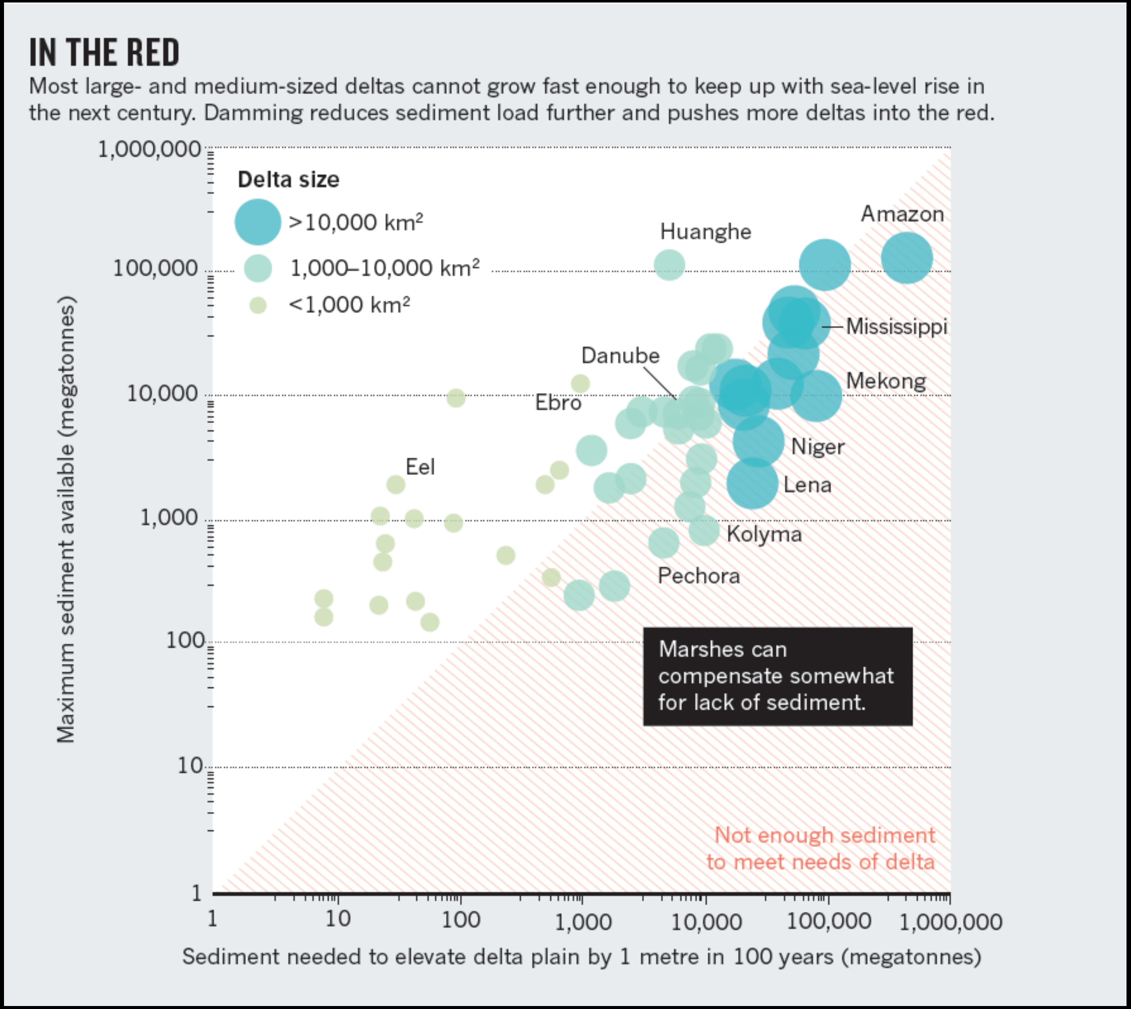
Grill et al. (2015) *Env. Res. Lett.*

Reduction in Missouri River Particulates from Damming



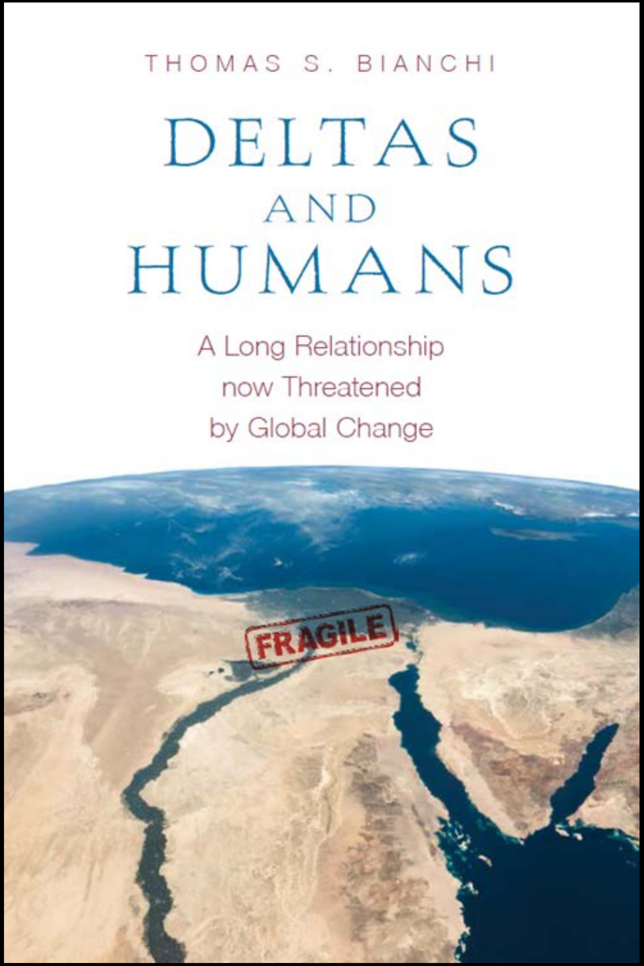
Meade and Mooney (2010) *Hydrol Proc.*

The Loss of Coastal Deltas



Giosan et al. (2014) *Nature*

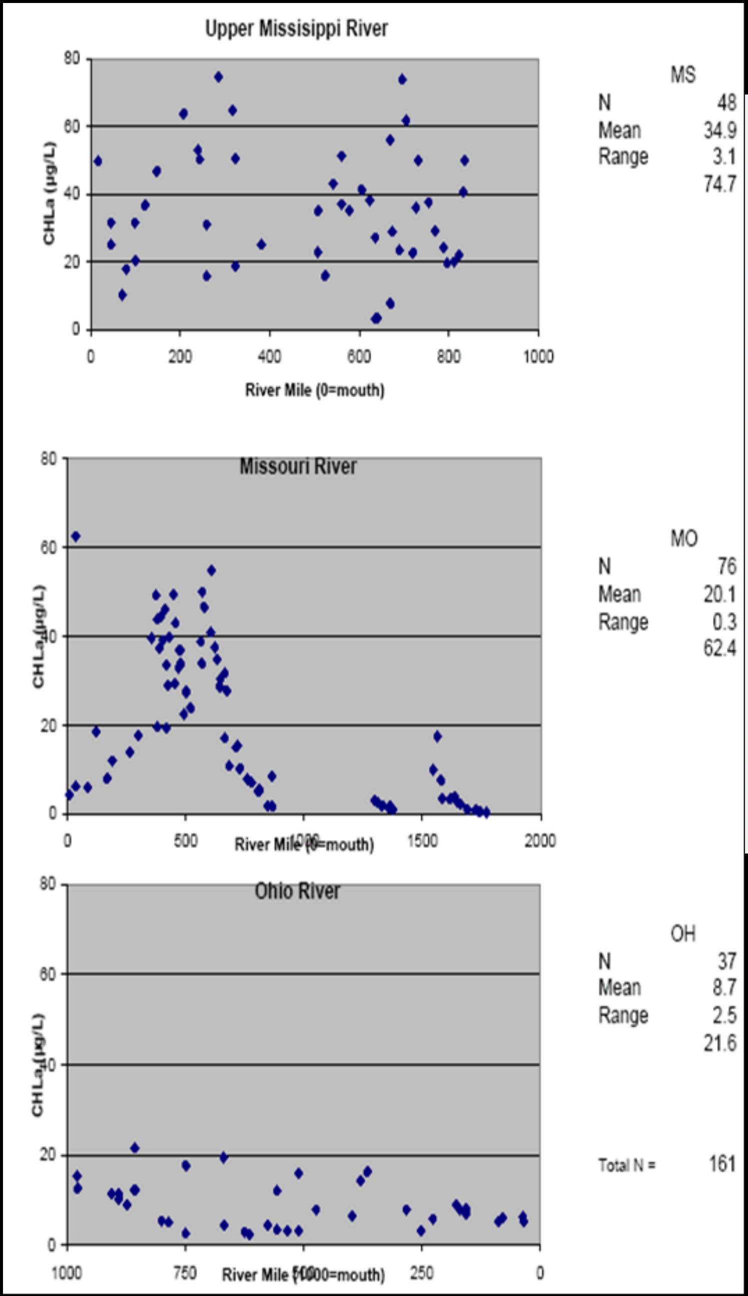
Shameless Advertising

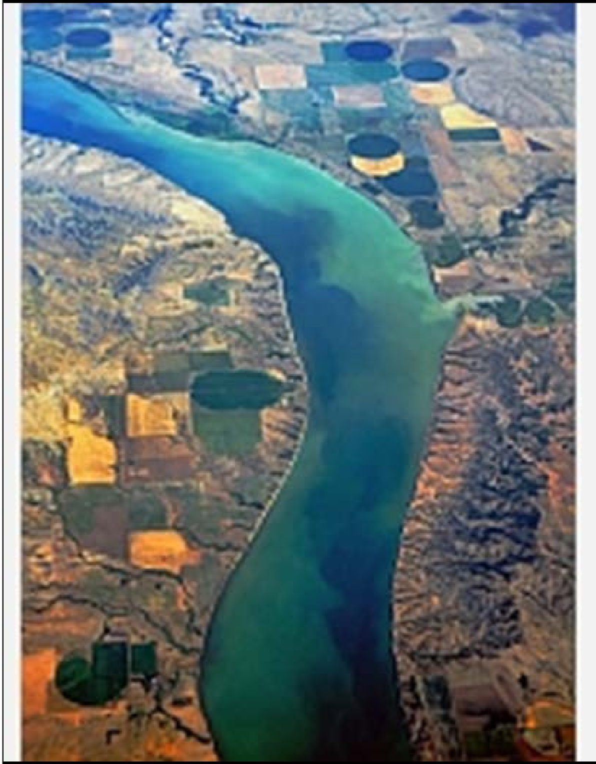


Bianchi (2016) Oxford Univ. Press

Slow the Flow and Phytoplankton will Grow

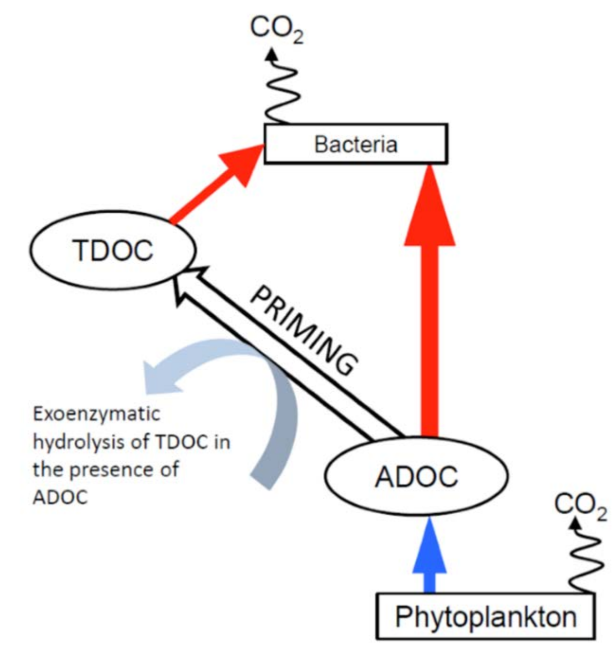
High phytoplankton biomass from backwater reservoirs, navigation locks of tributaries are exported to mainstem of river during high-flow periods



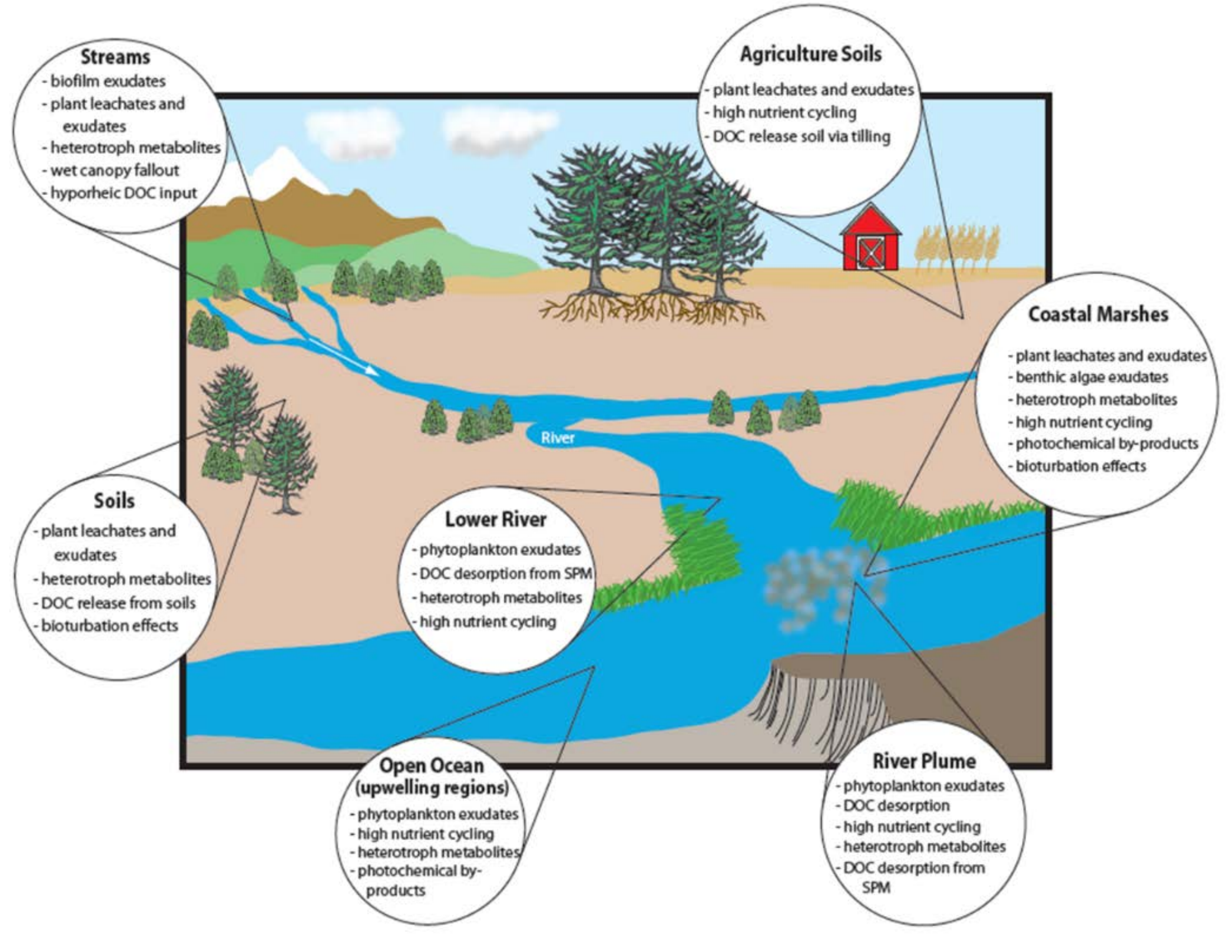


Duan and Bianchi (2006)
J. Geophys. Res.

Priming in the Aquatic Continuum



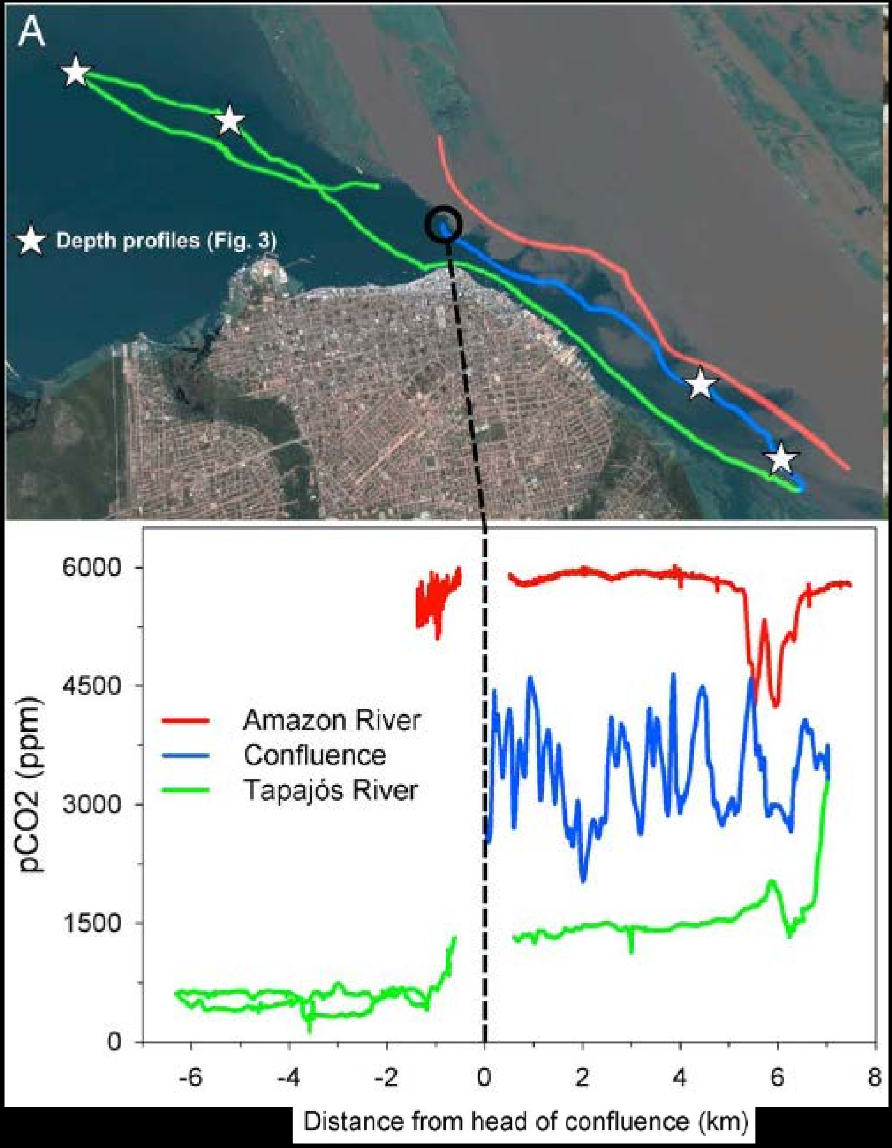
Bianchi et al. (2015) *Geophys. Res. Lett.*

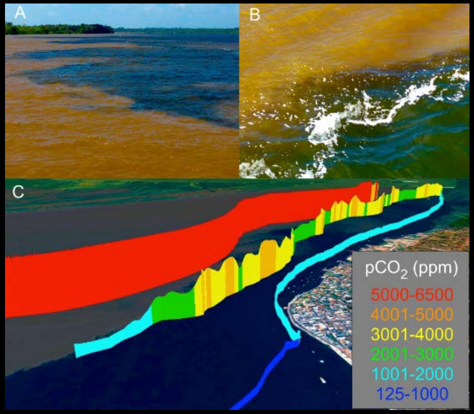


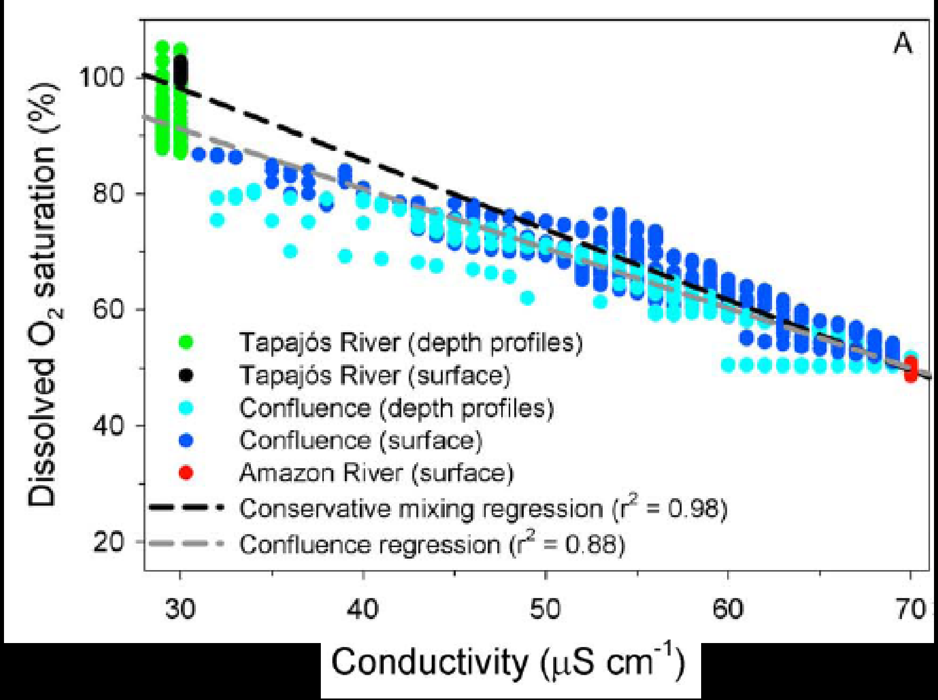
Bianchi (2011) *Proc. Nat. Acad. Sci.*

Recent evidence for priming in aquatic systems: Guenet et al. (2014) *Ecol.;* Bianchi et al. (2015) *Geophys. Res. Lett.;* Ward, Bianchi et al. (2017) *J. Geophys. Res.*

Priming at the River Confluence

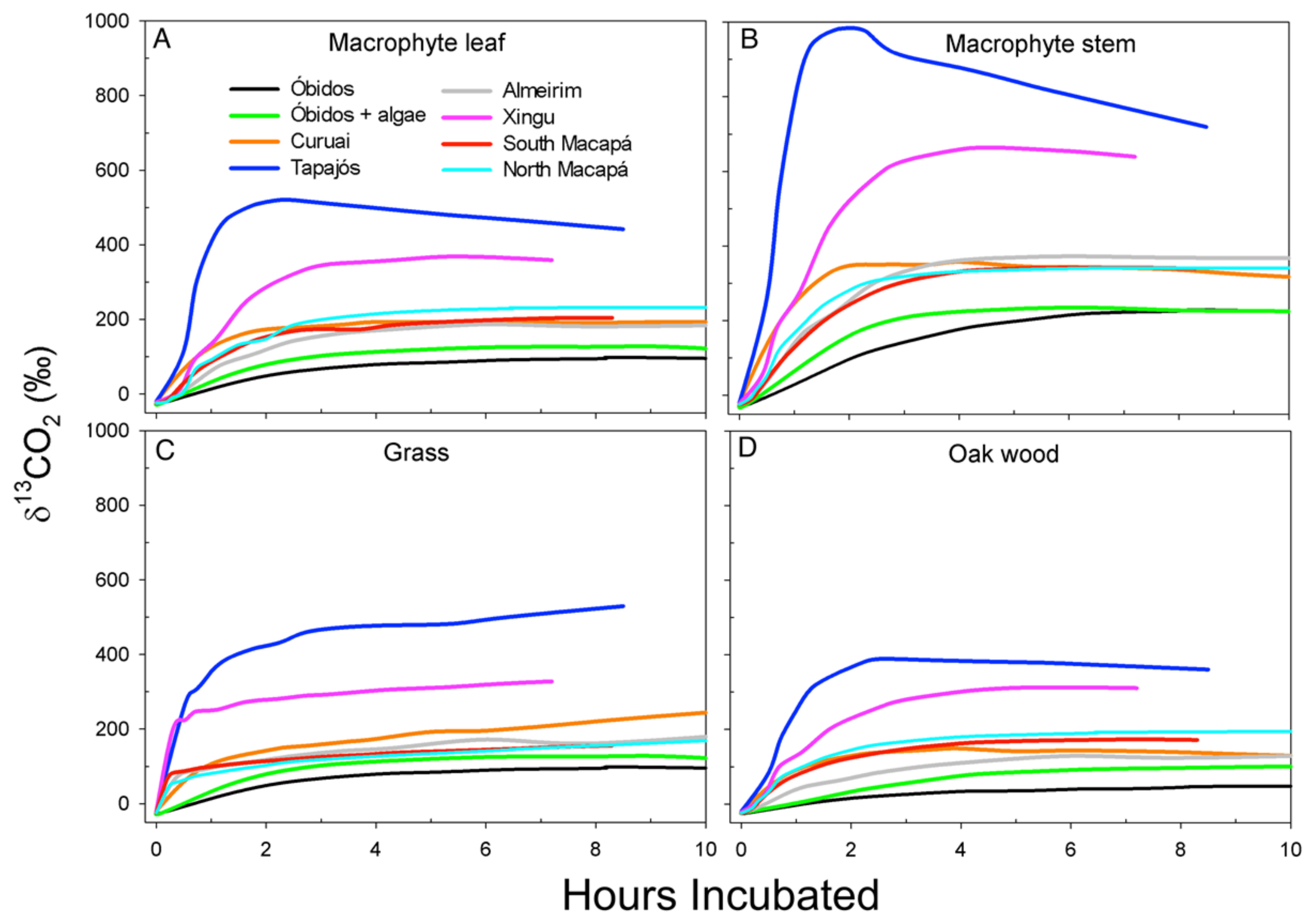






Ward, Bianchi et al. (2016) *J. Geophys. Res.*

Priming of Plant Leachates to CO2 at River Confluence



Relative to Óbidos,the sum degradation rate of all four leachates was 3.3 and 2.6 times faster in the algae-rich Tapajós and Xingu Rivers, respectively.

Ward, Bianchi, et al. (2016) *J. Geophys. Res.*

Possible “Hot Spots” for Priming in the Aquatic Continuum

Reservoirs

River Confluences

River Plumes

Organic Carbon Dynamics in Fjords

Organic Carbon Burial in Fjords and Ocean Sediments

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nature geoscience

PORPHYRY COPPER
Tracer of erosion

PLUMES AND RIDGES
Long-term links

NEOPROTEROZOIC OCEANS
Sulphide removed

Rapid carbon burial in fjords

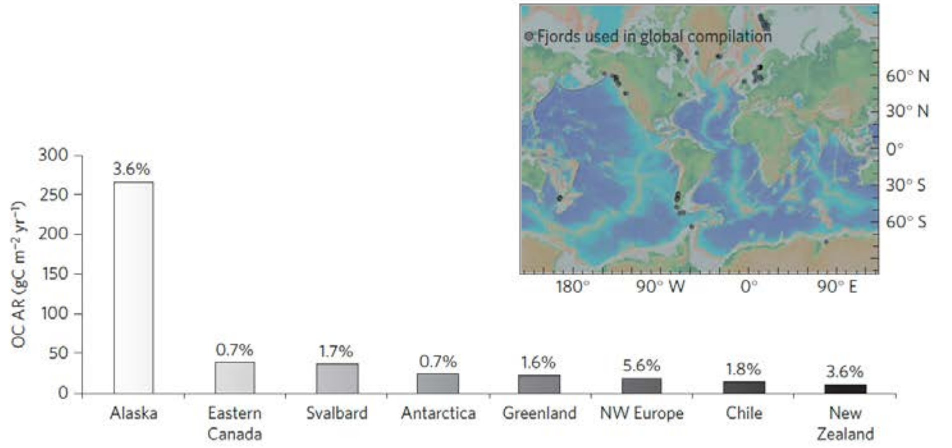
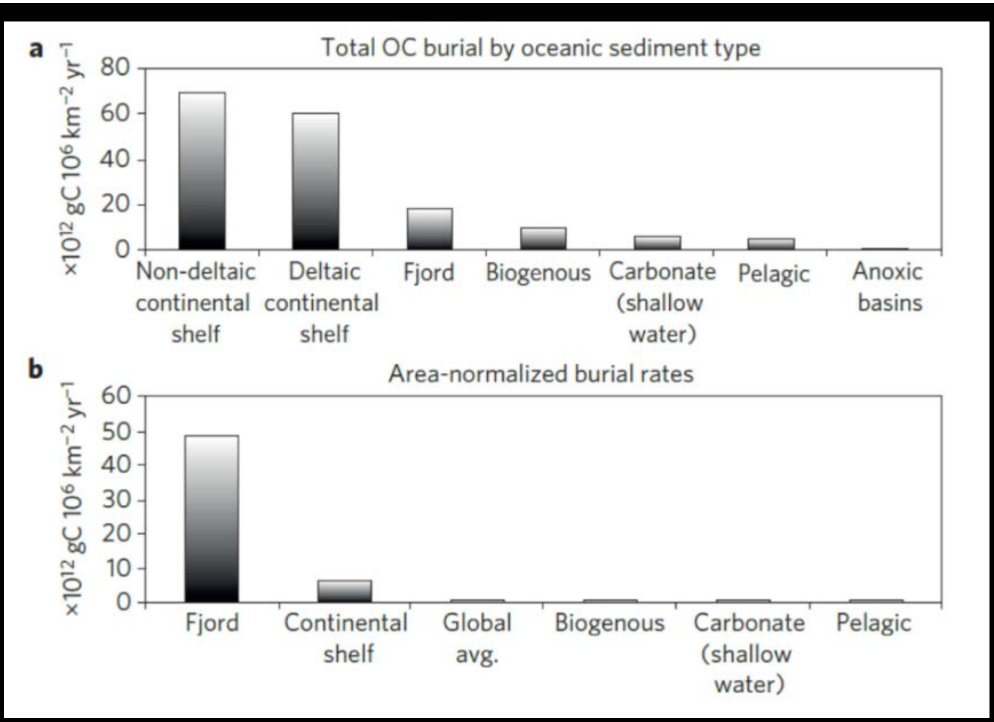


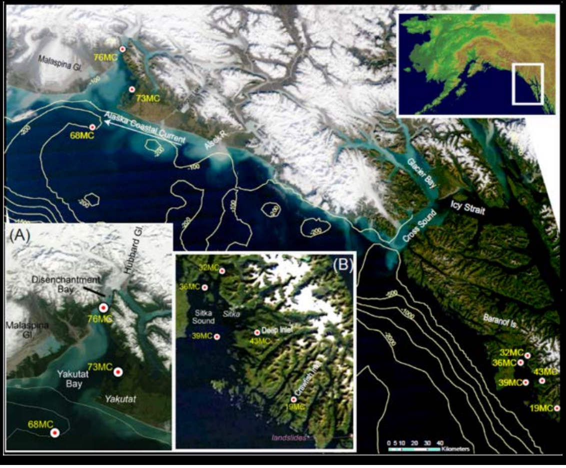
Figure 1 | Organic carbon concentration and accumulation data were compiled from 573 globally distributed fjord sediment samples and 124 cores (locations shown on map insert). Bars represent the area-normalized average organic carbon accumulation rate (OC AR) of each fjord region. Shown above each bar is the average OC content of surface sediments (%OC_{sfc}) in fjord basins.

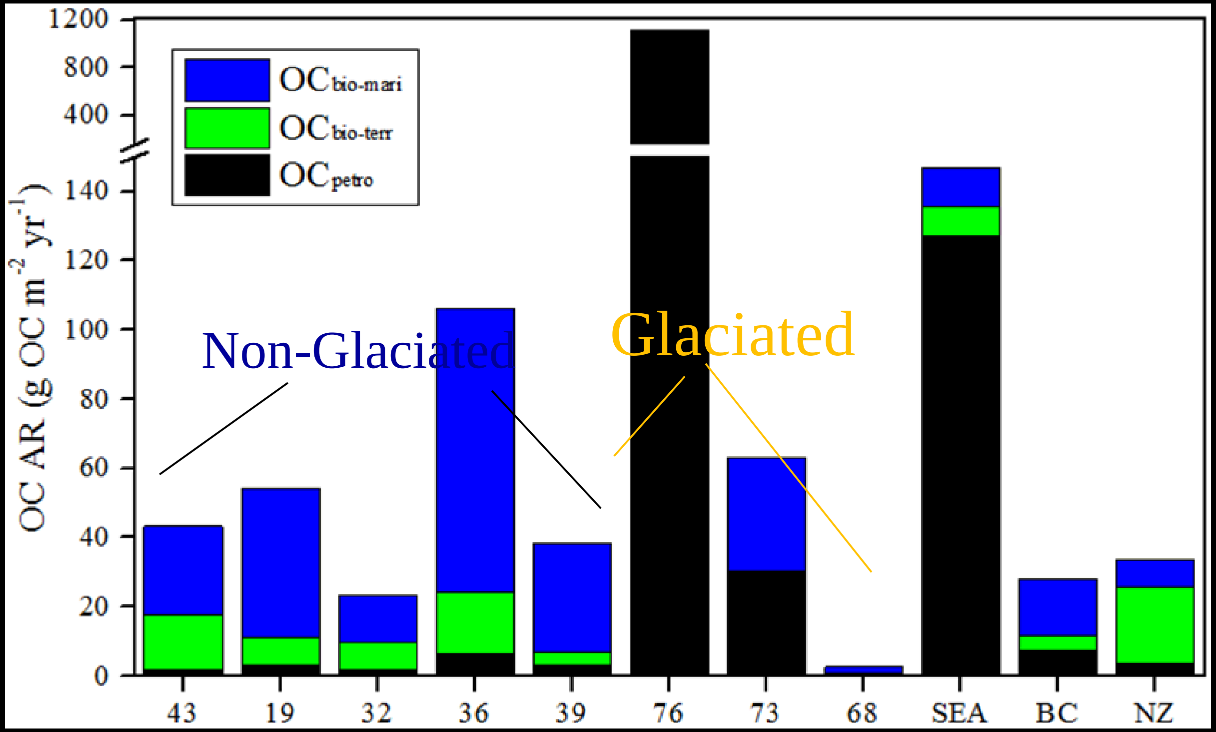


It was estimated that fjords store ca. 11% of annual marine carbon burial globally.

Smith, Bianchi et al. (2015) *Nat. Geosci.*

Biospheric and Petrogenic OC Flux along Southeast Alaska

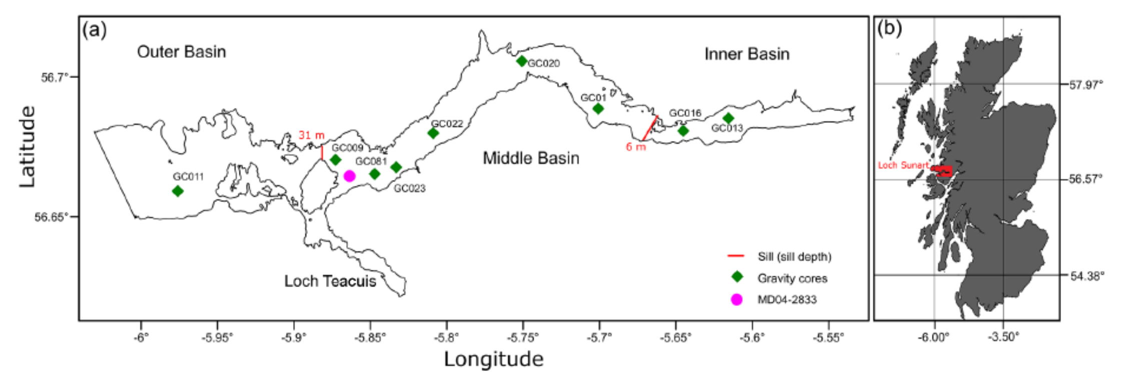




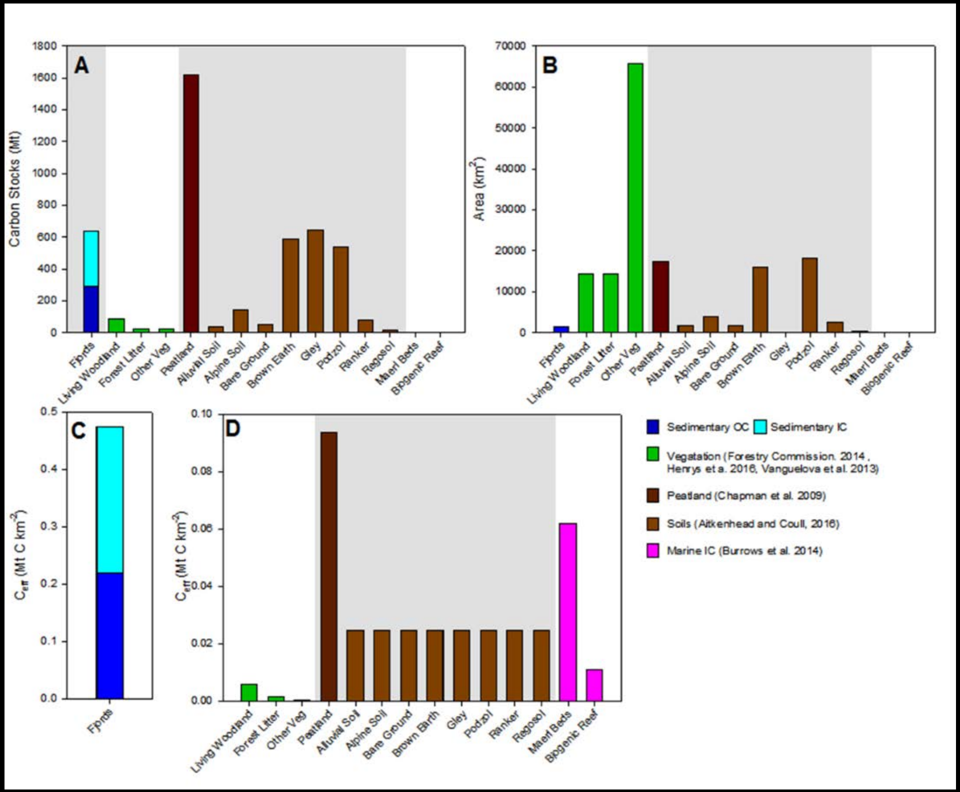
Using end-member mixing models, we determined that glaciated fjords have significantly higher burial rates of petrogenic OC$_{petro}$ (1113 g OC m-2 yr-1), than non-glaciated fjords in SE Alaska - which are effective in burying marine OC (OC$_{bio\text{-}mari}$) (13 - 82 g OC m-2 yr-1).

Cui, Bianchi et al. (2016) *EPSL*

Carbon Storage in Scotland



Smeaton et al. (2016) *Biogeosci.*

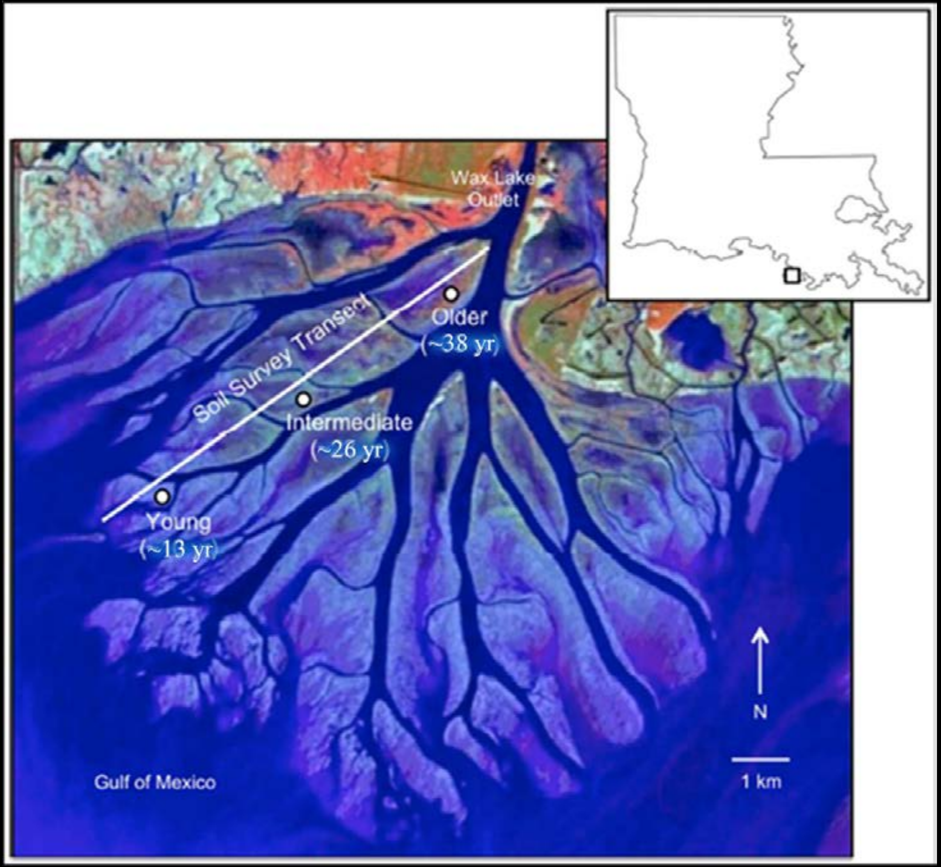


Despite the smaller areal extent of fjords relative to peatlands in Scotland, C storage is an order of magnitude greater in them.

Smeaton et al. (In review, *EPSL*)

Carbon Sequestration in Wetlands on an Embryonic Delta and Coastal U.S Wetlands

Carbon Burial in an Embryonic Delta



This delta formed as a result of the construction of the **Wax Lake** outlet in 1941. The outlet was built to provide flood relief for the lower Atchafalaya River.

Shields, Bianchi et al. (2015) *Geophys. Res. Lett*

Chronosequence

13 years old

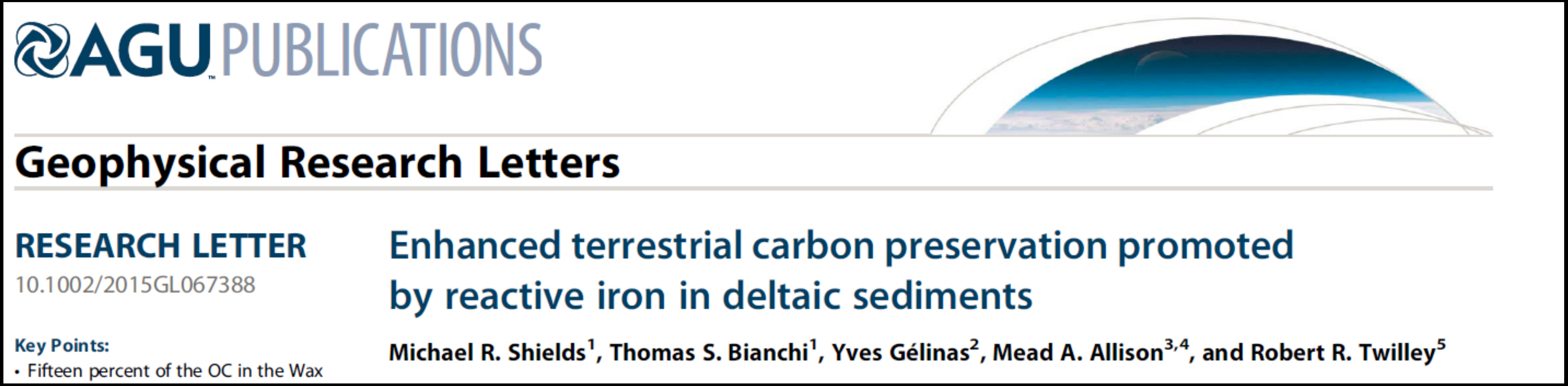
26 years old

38 years old

These study sites, which became subaerial at different times, evolved in vegetation type, OC source, and biogeochemical pathways

Henry and Twilley (2014) *Ecosystems*

Role of Reactive Iron in OC preservation



AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2015GL067388

Key Points:

- Fifteen percent of the OC in the Wax

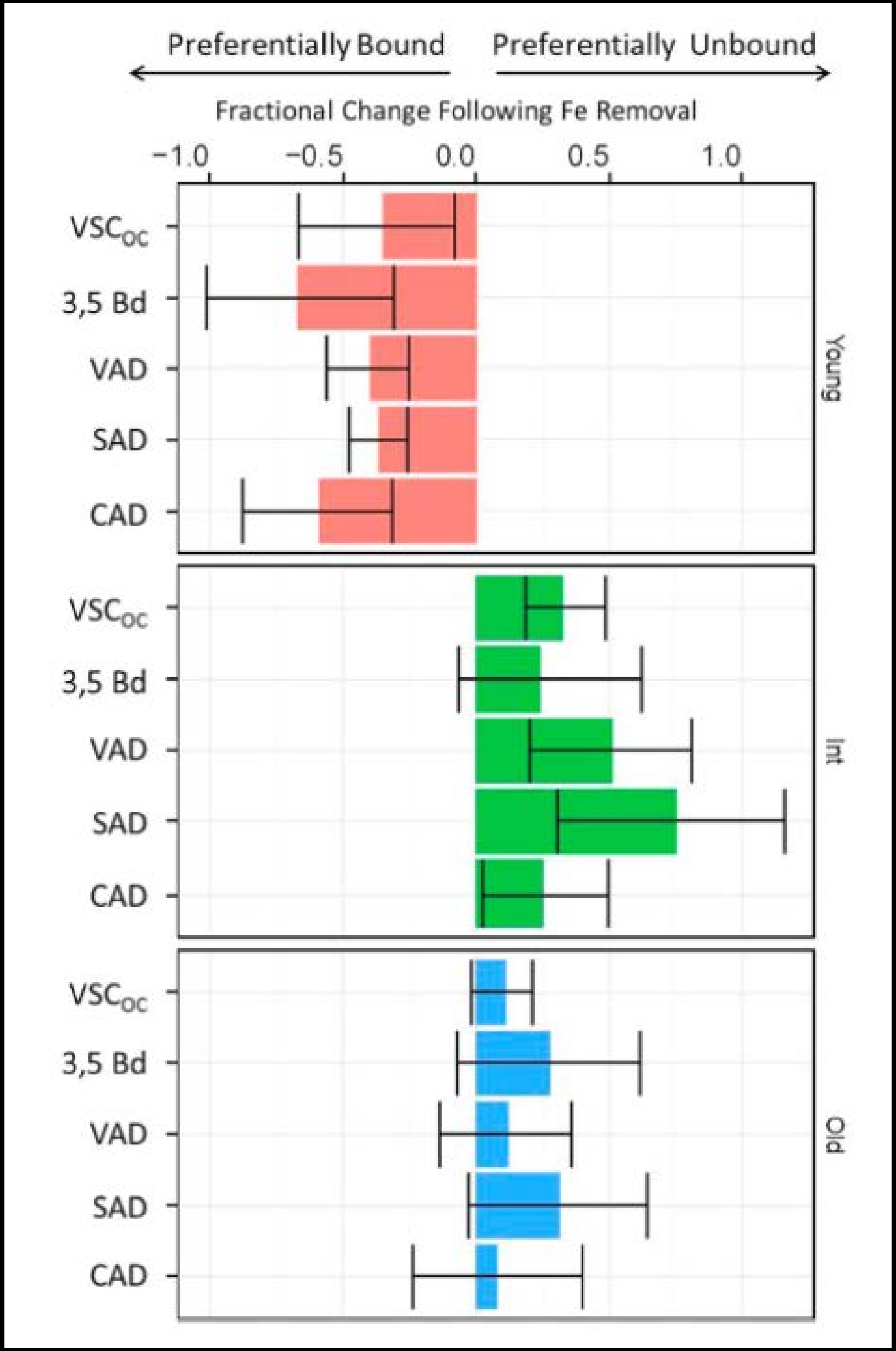
Enhanced terrestrial carbon preservation promoted by reactive iron in deltaic sediments

Michael R. Shields[1], Thomas S. Bianchi[1], Yves Gélinas[2], Mead A. Allison[3,4], and Robert R. Twilley[5]

~15.0% of the OC was bound to FeR, and the dominant binding mechanisms varied from adsorption in the youngest subaerial region with the .

Shields, Bianchi et al., (2016) *Geophys. Res. Lett.*

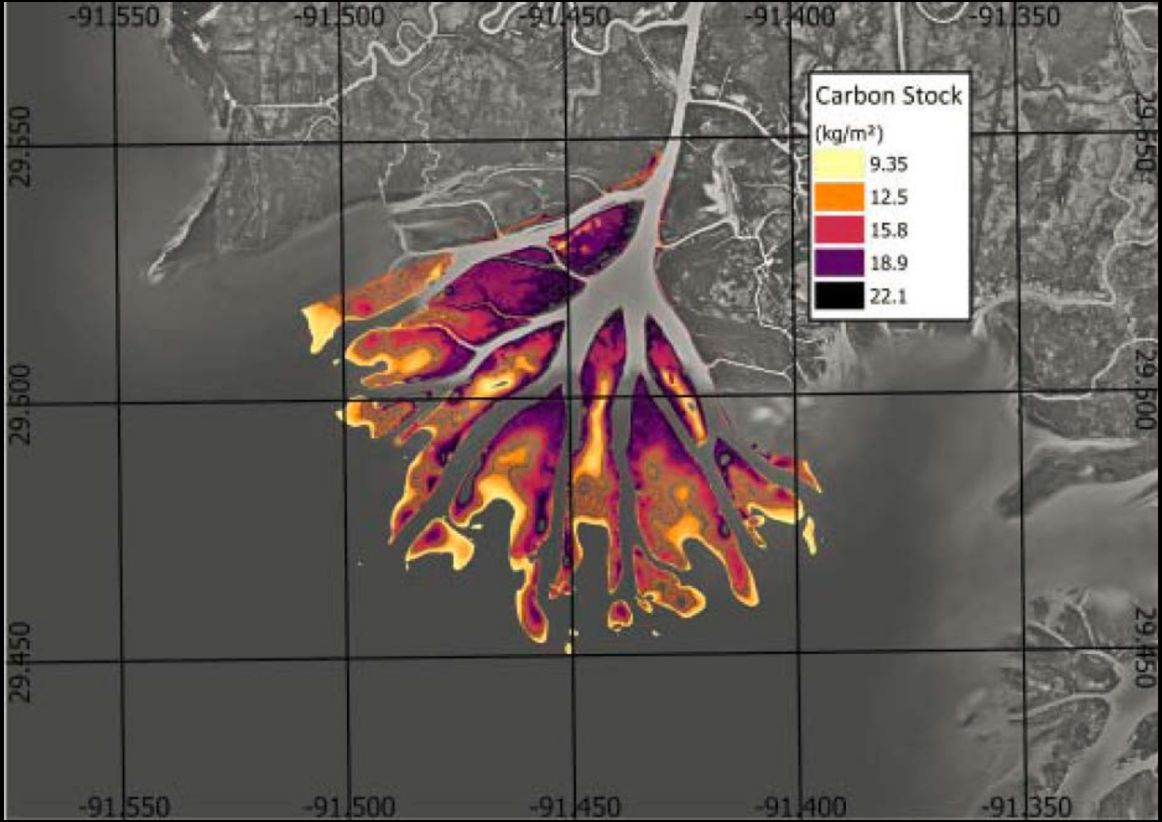
Preferential Sorption of Select Compounds

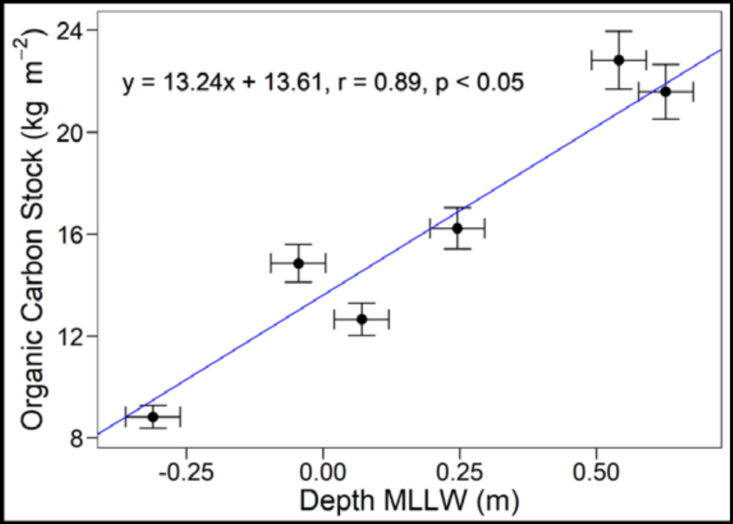


Lignin phenols and aromatic acids are preferentially sorbed to FeR (OC:Fe<1) at the Young site but are not preferentially bound during co-precipitation at the Intermediate and Old sites.

Shields, Bianchi et al. (2015) Geophys. Res. Lett

Carbon Stock and Elevation

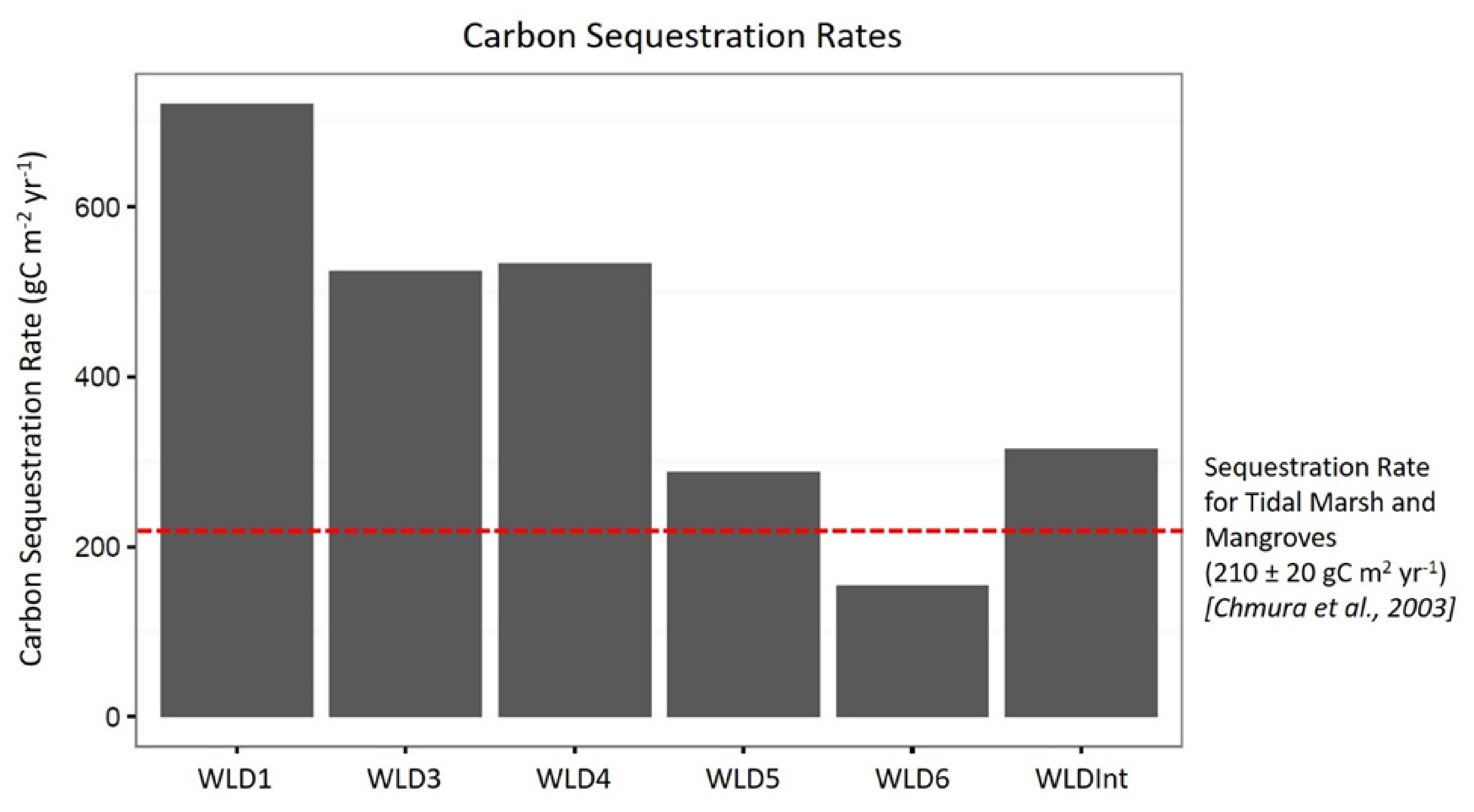




Elevations are referenced to mean lower low water (MLLW).

Shields, Bianchi, et al. (2017) *Nat. Geosci.*

Global Comparison of Carbon Sequestration Rates

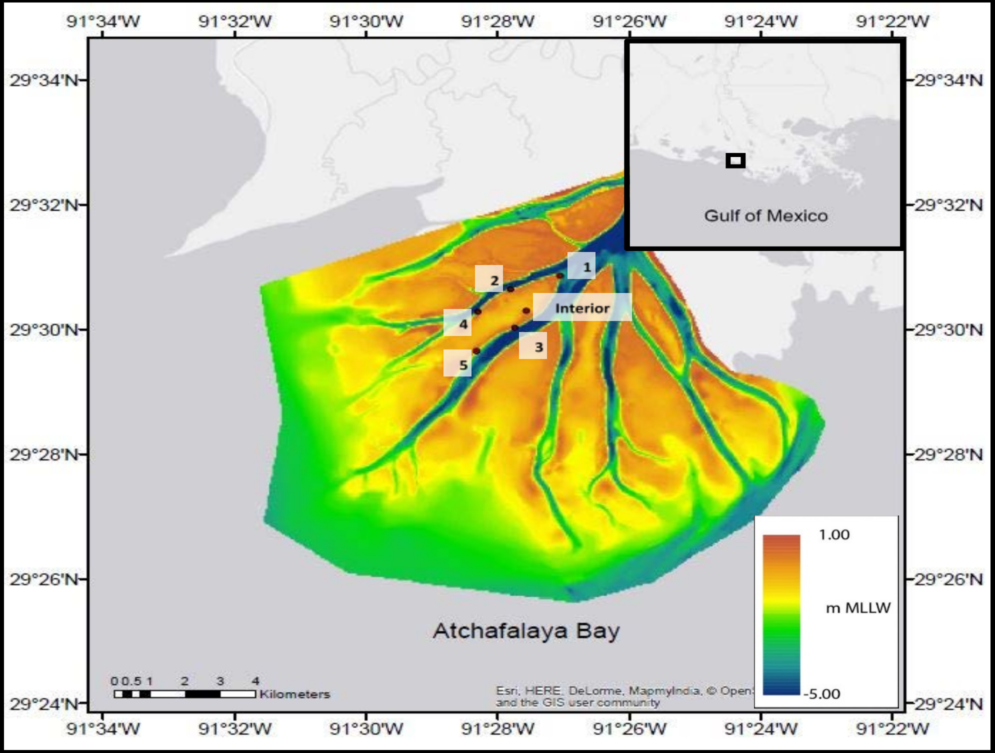


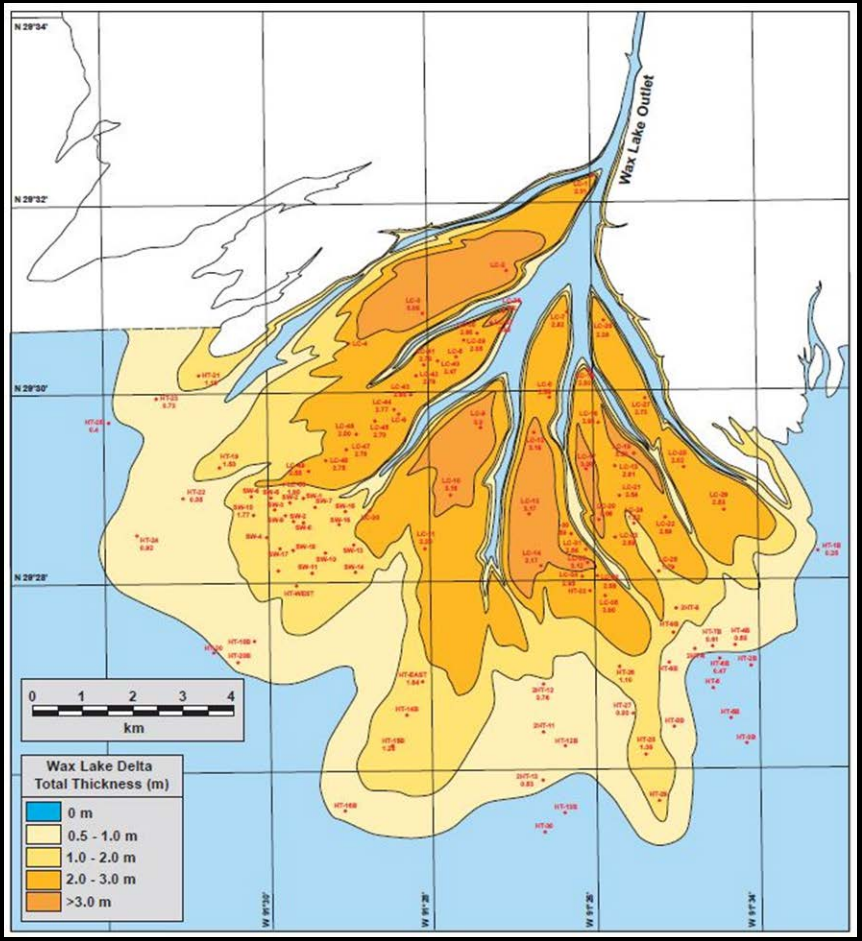
Sequestration Rate
for Tidal Marsh and
Mangroves
(210 ± 20 gC m^2 yr^{-1})
[Chmura et al., 2003]

Shields, Bianchi, et al. (2017) *Nat. Geosci*.

Ecogeomorphology

Sampling Sites and Delta Thickness



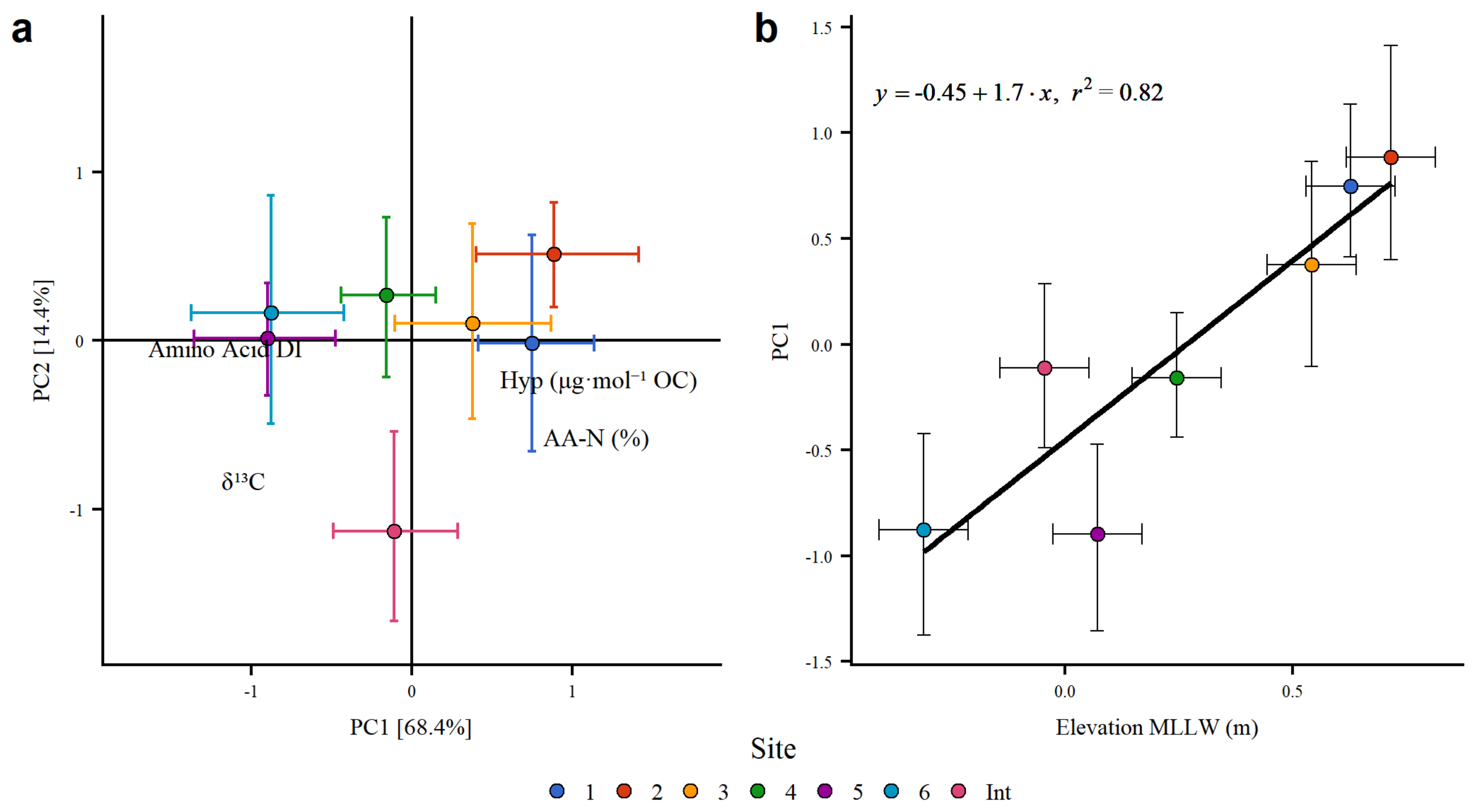


Elevations are referenced to mean lower low water (MLLW).

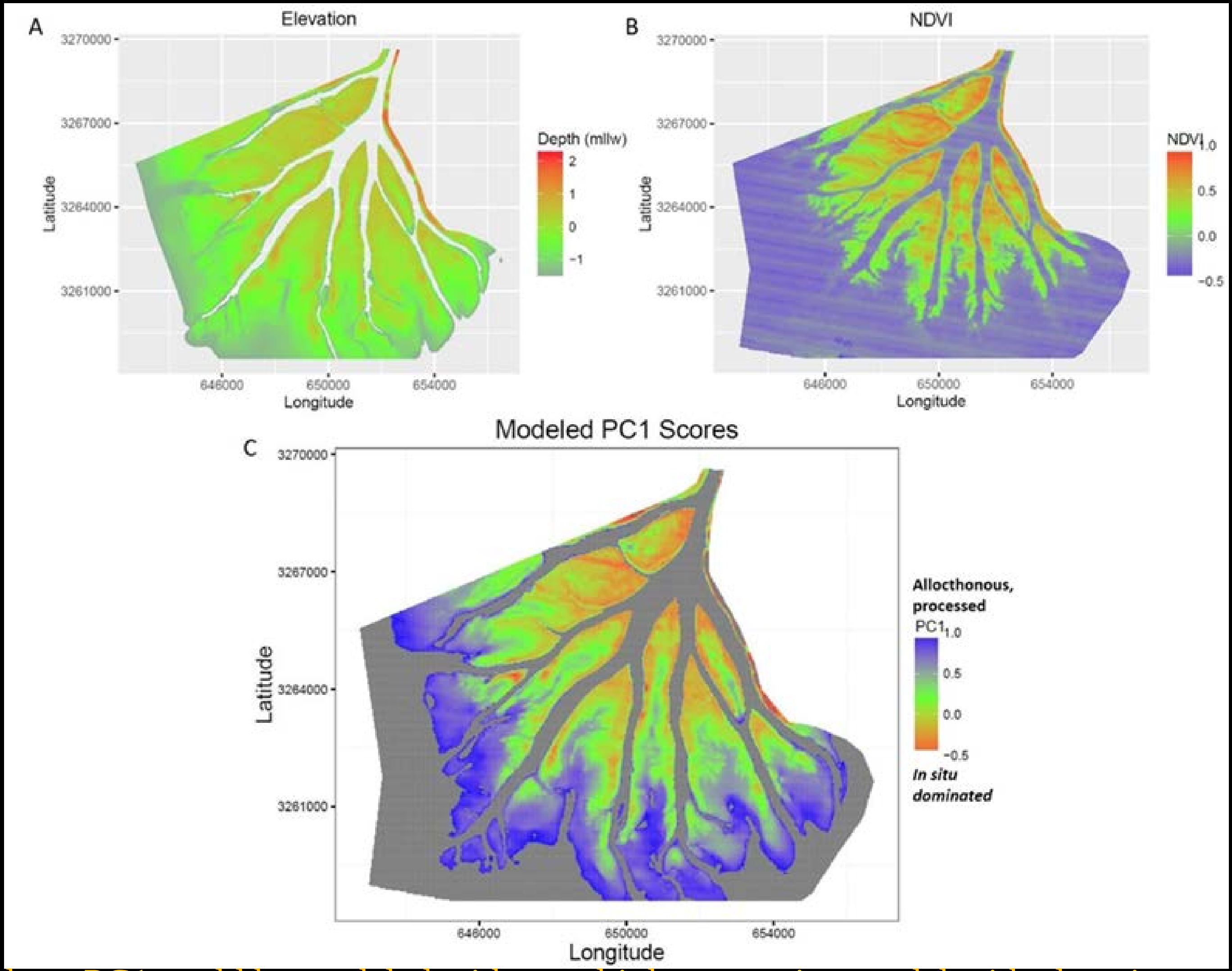
Vibracore samples collected at 120 locations Wellner (2005)

Shields, Bianchi et al. 2018 *Limnol. Oceanogr.* (provisionally accepted)

Ecogeomphology Model



Shields, Bianchi et al. 2018 *Limnol. Oceanogr.* (provisionally accepted)



The scores along PC1 could be modeled with a multiple regression model with elevation and NDVI as the predictive variables ($p < 0.05$, r2 = 0.80) in the following equation:

PC1 score= -0.53(elevation)+ -0.57(NDVI)+0.39

Where, elevation is the site elevation in the DEM model, and NDVI is the mean NDVI for each site from June 2014 to July 2015.

Final Thoughts

A Need for more Critical Zone Dynamics in the Aquatic Continuum

Critical Zone Science

Atmosphere ↕ Biosphere ↕ Hydrosphere ↕ Lithosphere

Minutes ↘ Decades ↘ Millenia ↘ Eons

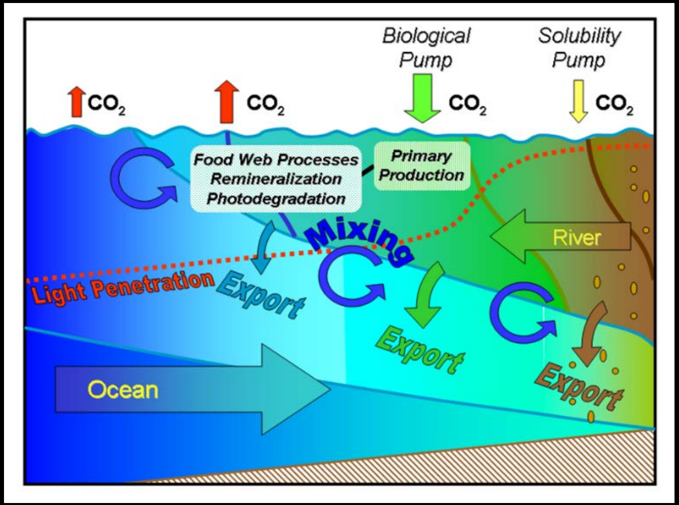
Hillslope ↔ Catchment ↔ Watershed

Earth's permeable near-surface layer from the tops of the trees to the bottom of actively cycling groundwater.

- Where rock, soil, water, air, and living organisms interact and shape the Earth's surface
- Critical to sustaining the earth's sustaining services
  - Clean water
  - Productive soil
  - Balanced atmosphere

Chorover et al (2007) *Elements*

Ward, Bianchi et al. (2017) *Front. Mar. Sci.*



Lohrenz et al. (2014)