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

Thomas S. Bianchi

Jon and Beverly Thompson Endowed Chair
of Geological Sciences
University of Florida

Funding

NSF

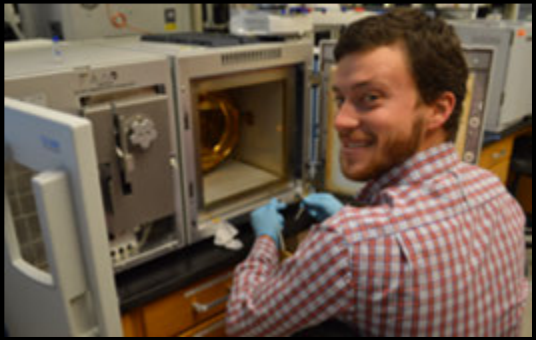
NASA

U.S. DEPARTMENT OF ENERGY

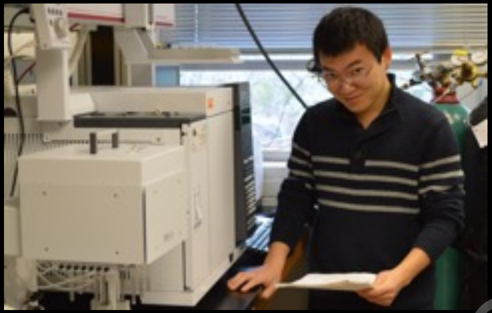
NSFC
National Natural Science Foundation of China

The Bianchi Lab

Key Players From Bianchi Lab

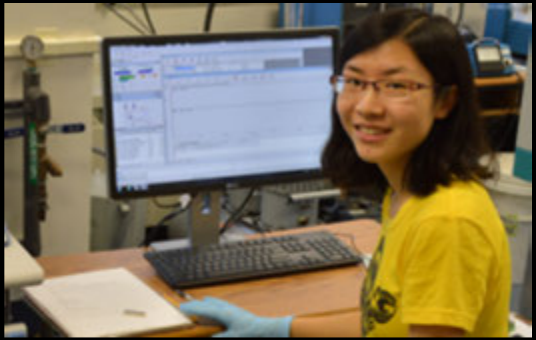


Michael Shields, Postdoc at UF



Xingqian Cui, Postdoc at MIT

Elise Morrison, Postdoc UF



Xiaowen Zhang, Postdoc at MIT

Rick Smith, Global Aquatic Res., Inc.

Nick Ward, at PNNL

Research Associate, Washington Univ.

Derrick Vaughn, Postdoc FSU

Seminar Outline

1. "Hot Spots" and Controls of Organic Carbon Burial

2. Changing Carbon Dynamics in the Anthropocene

3. Macrobenthos on the Move in Aquatic Critical Zones: Implications for Carbon Storage

The Bianchi Lab

“Hot Spots” and Controls of Organic Carbon Burial

Burial of Sedimentary Organic Carbon (OC)

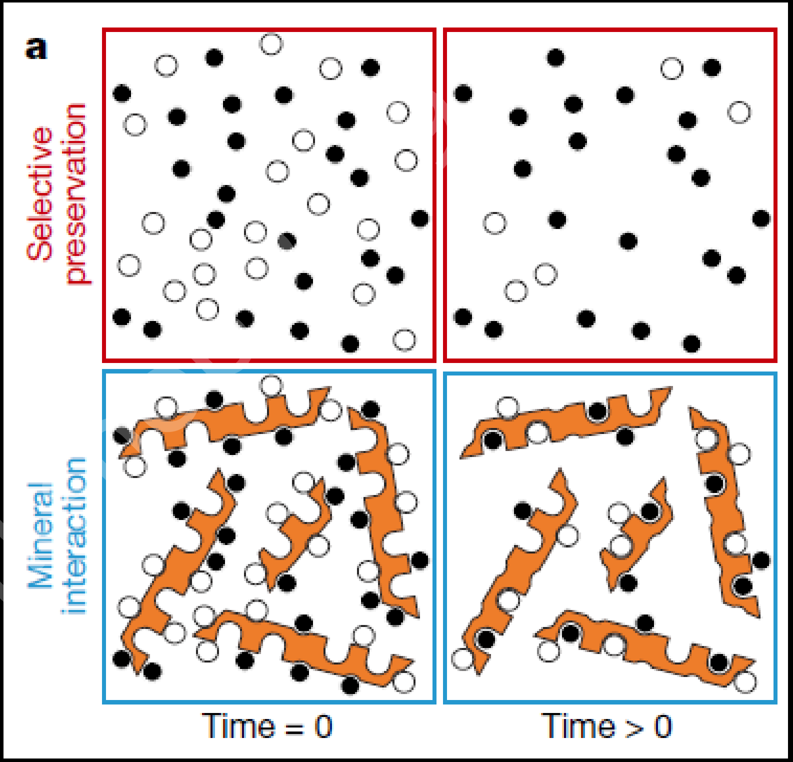
Most OC (ca. 86%) is preserved in continental margin sediments (Berner, 1982; Hedges, 1992; Burdige, 2005, 2006; Smith et al., 2016; Cui et al., 2017; Bianchi et al., 2016, 2018; Middelburg, 2018).

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

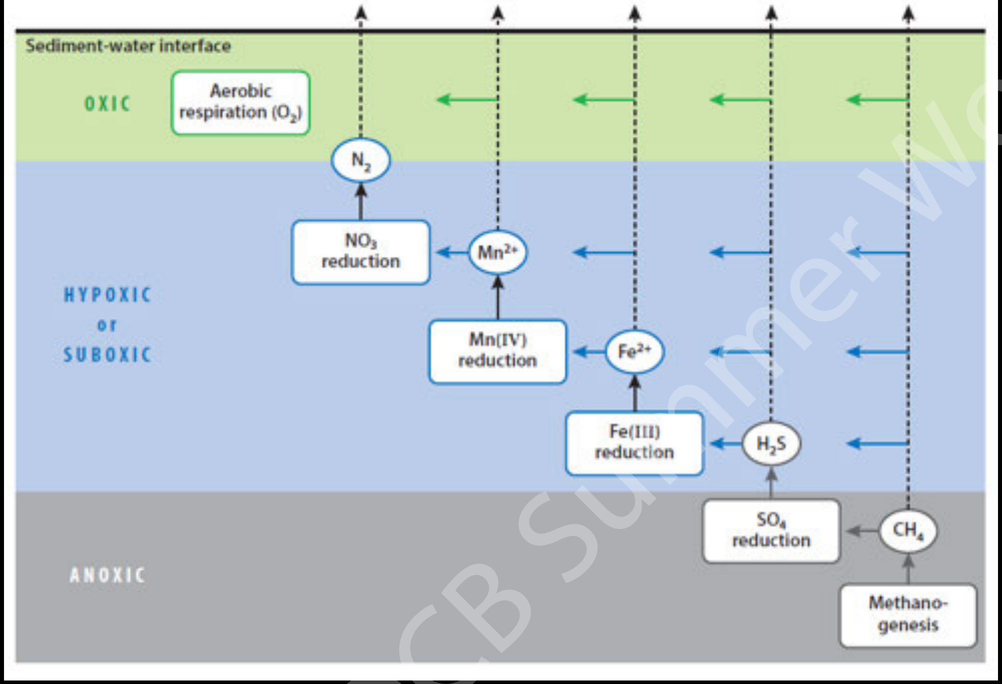
The Bianchi Lab

Redox and Mineral-Binding Effects



Selectivity vs. Protection

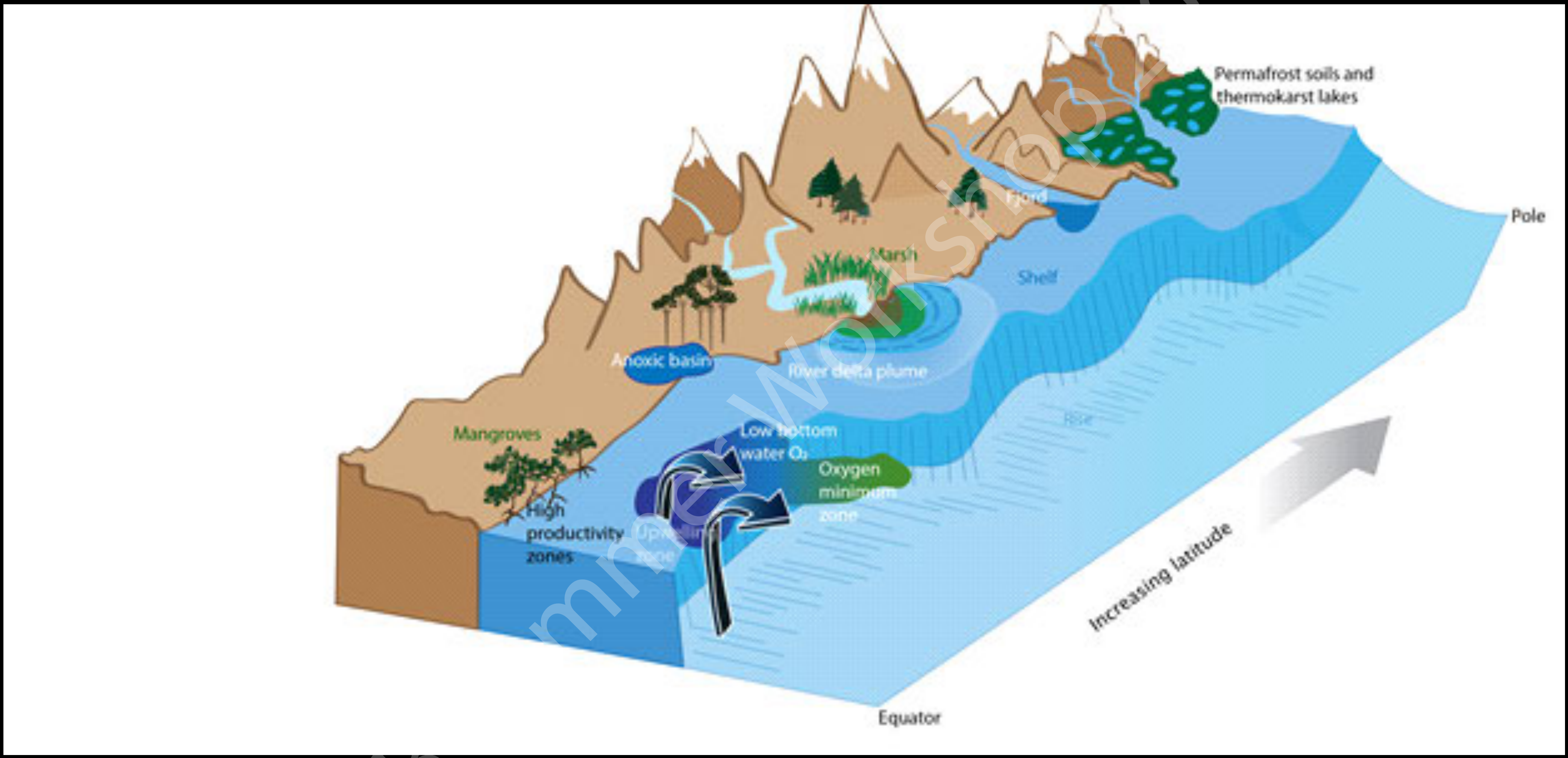
Hemingway et al. (2019) *Nature*



Bianchi et al. (2016) *Ann. Rev. Earth Planet Sci.*
Modified after Middelburg and Levin (2009) Biogeosci.

The Bianchi Lab

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



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

The Bianchi Lab

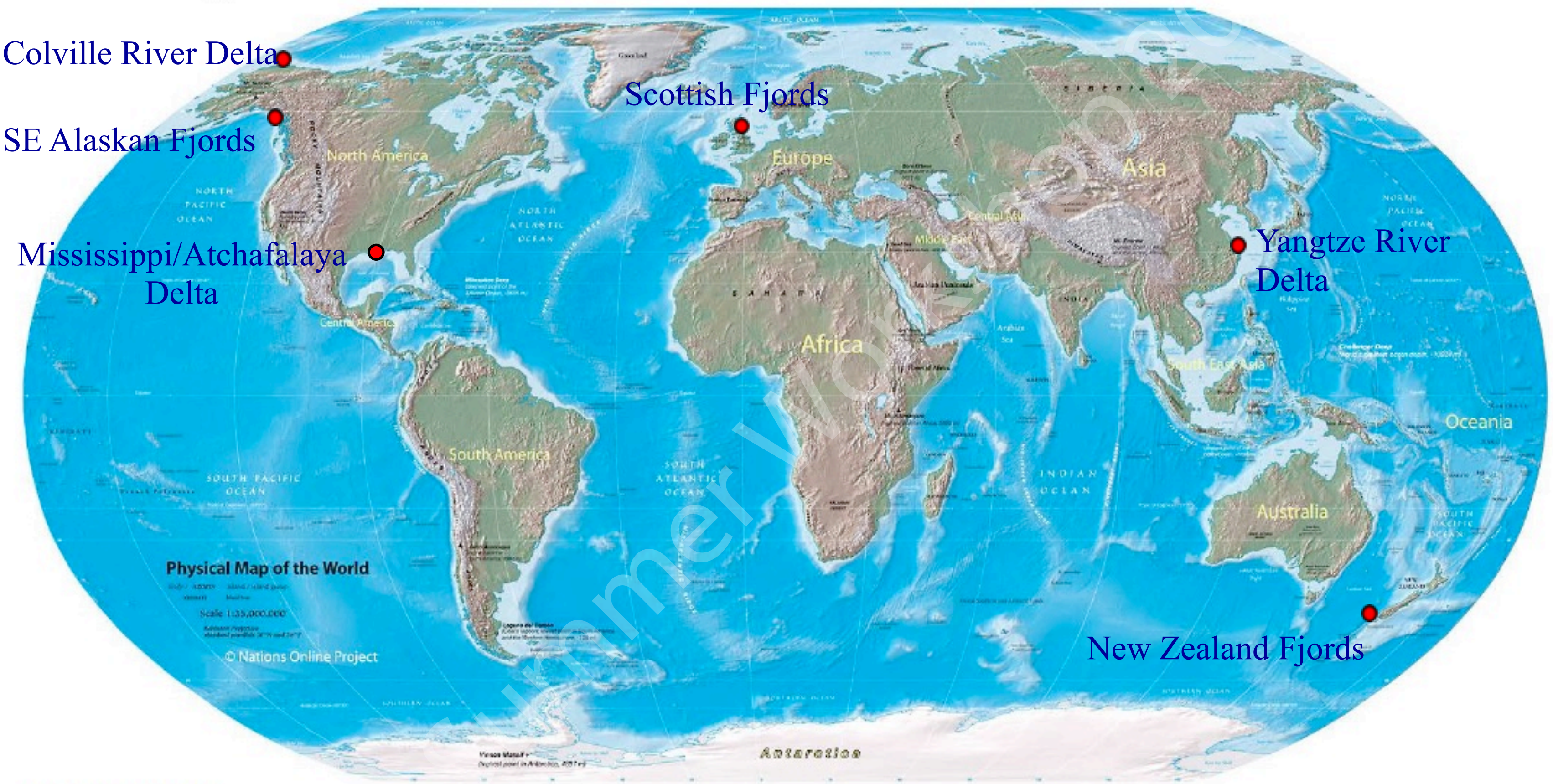
Have Global Carbon Stocks in Deep Ocean Sediments been Overlooked as a Carbon Reservoir?

Oligotrophic oxygenated ocean sediments <0.1%), stable to depths of 25 m and ages of 24 million years; estimated 1.6 × 10^22 g of organic carbon are sequestered on million-year timescales in oxic pelagic sediment.

Estes et al. (2019) *Nat. Geosci*

Changing Carbon Dynamics in the Anthropocene

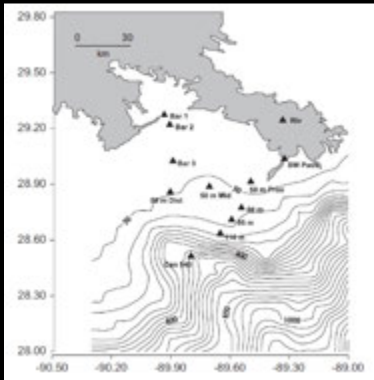
Coastal Study Sites



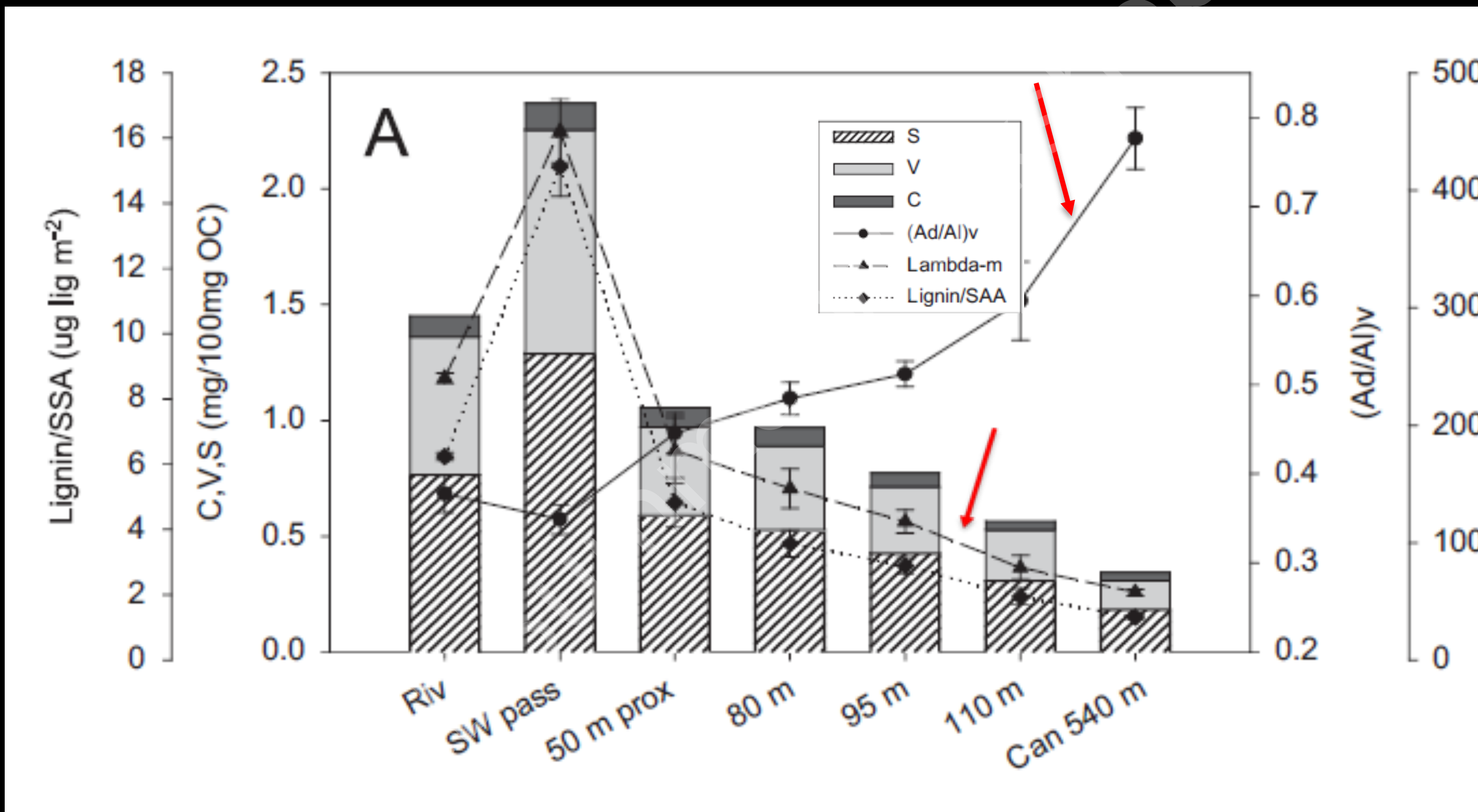
Physical Map of the World

global map.htm[7/6/2016 8:09:10 AM]

Transport and Decay of Lignin



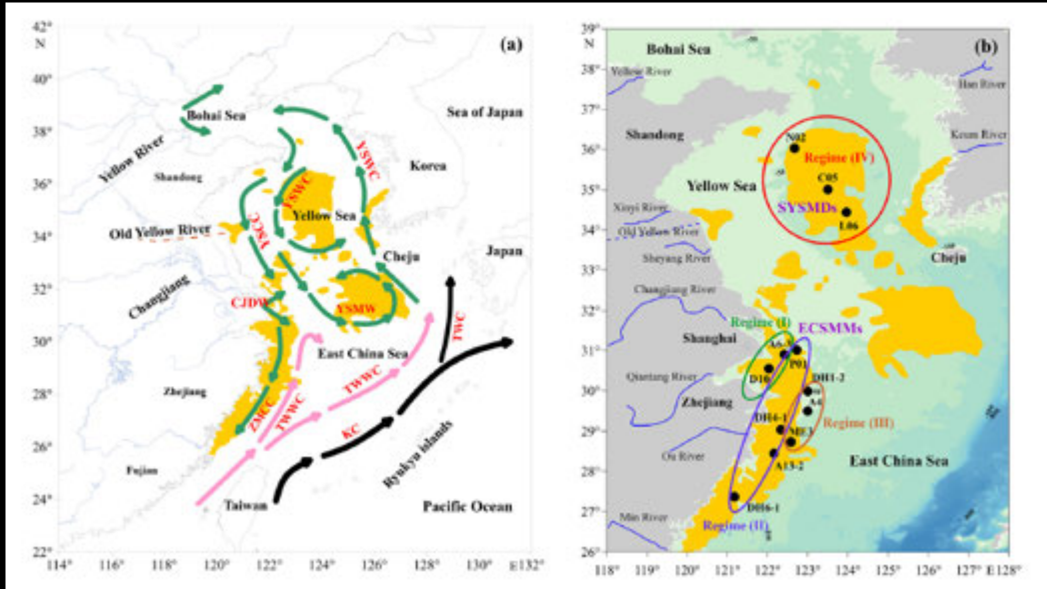
Lignin decreases across-shelf due in part to decomposition as evidenced by higher Ad/Al ratios, some loss may be due to transformation into other substances (e.g., carboxylic-rich alicyclic molecules [CRAM], personal comm. P. Hatcher).

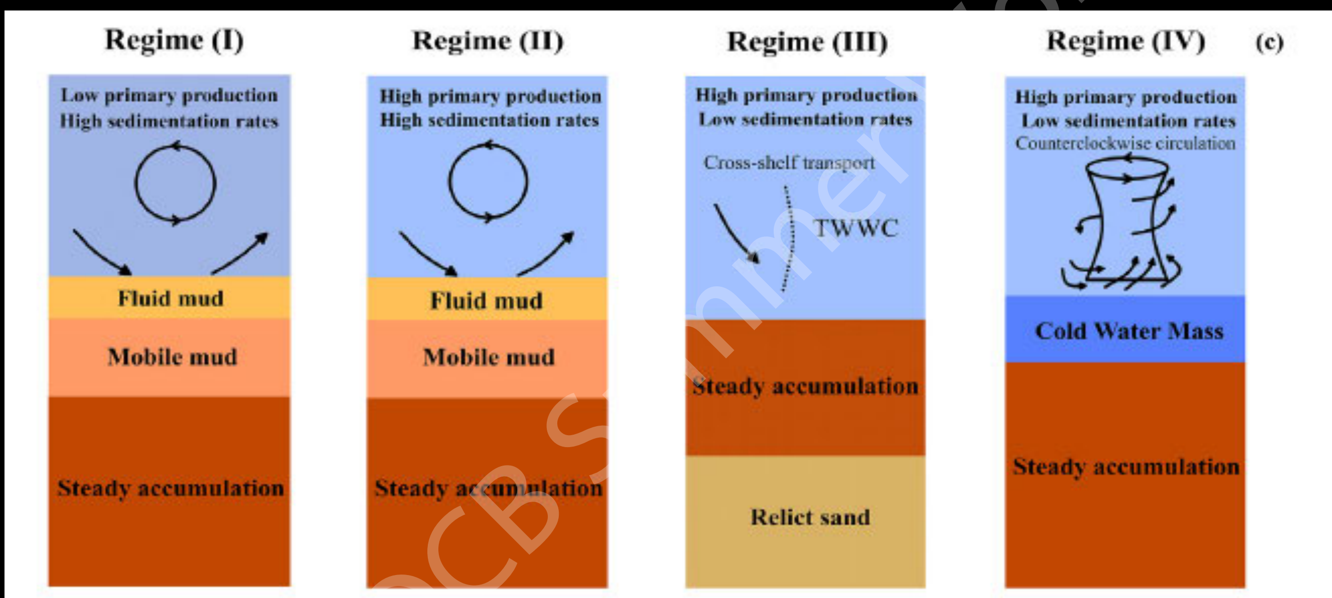


Sampere, Bianchi et al. (2008) *Cont. Shelf Res.*

The Bianchi Lab

Carbon Cycling Different Sedimentary Regimes



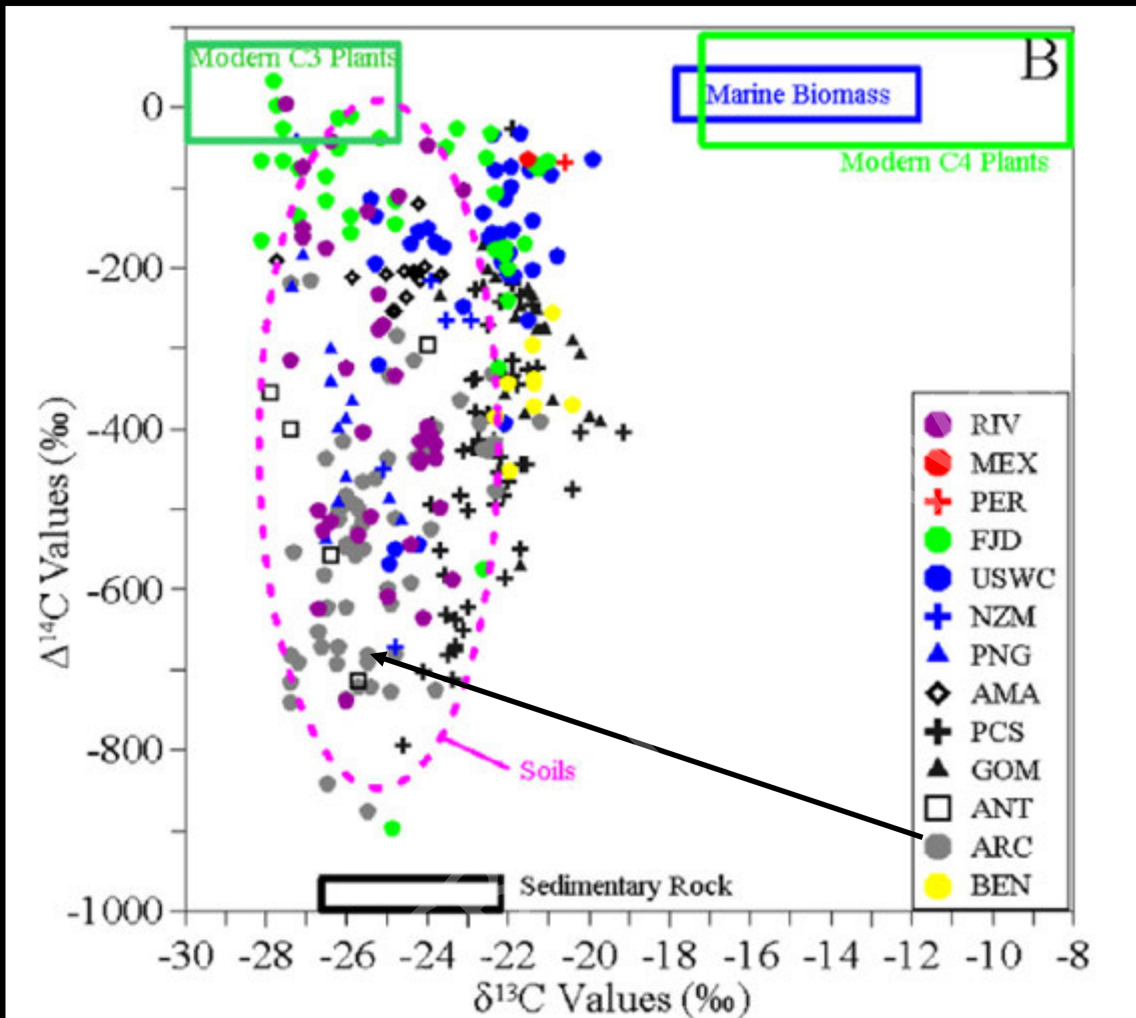


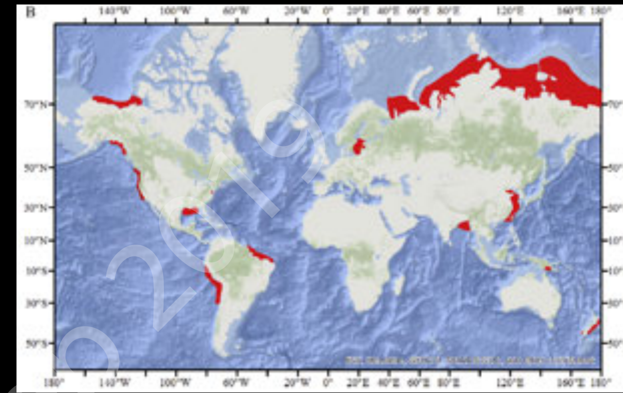
Based on incubation studies, an estimated 16.8% of SOC was decomposed in sediments of ECSMMs, but only about 5.4% of SOC was decomposed in SYSMDs.

Zhao, Bianchi et al. (2018) *Mar. Geol.*.

The Bianchi Lab

Pre-and Post-Depositional Effects on OC Age in Sediments



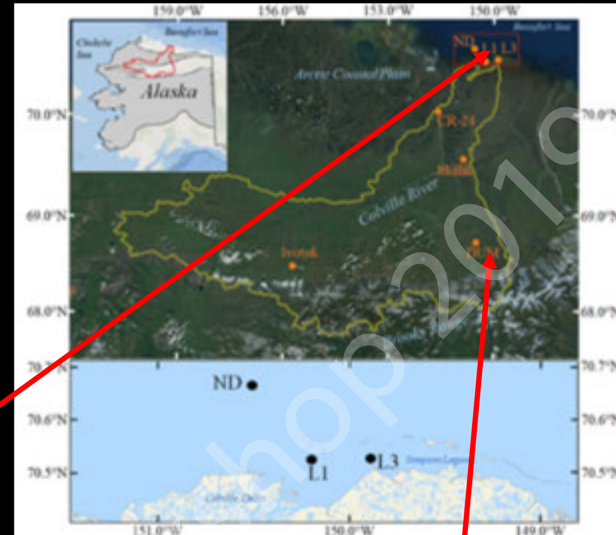


Samples from the pan-Arctic (ARC) show a greater percentage of markedly lower del-14C values that are attributed to release of pre-aged OC (e.g. from permafrost).

Bianchi et al. (2018) *Org. Geochem.*

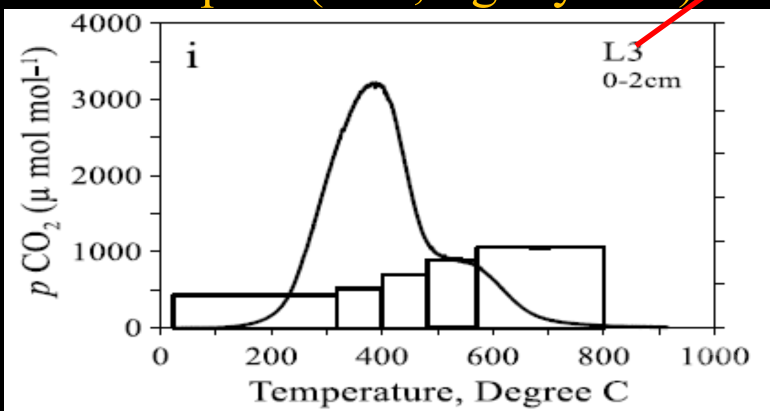
The Bianchi Lab

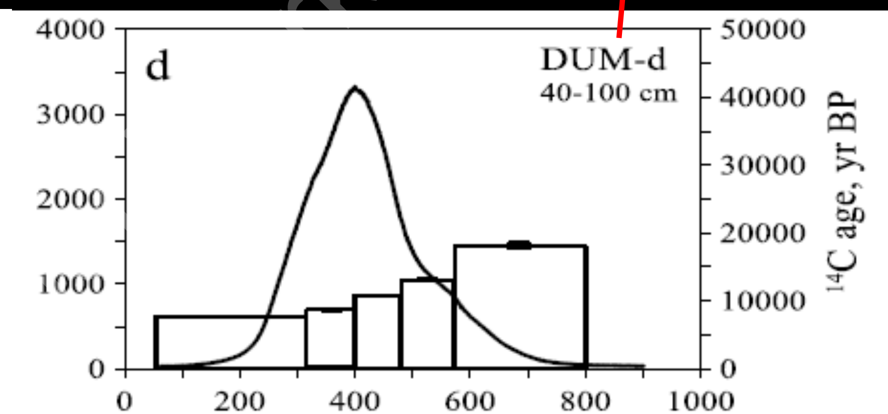
OC Permafrost Transport to Coast



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).



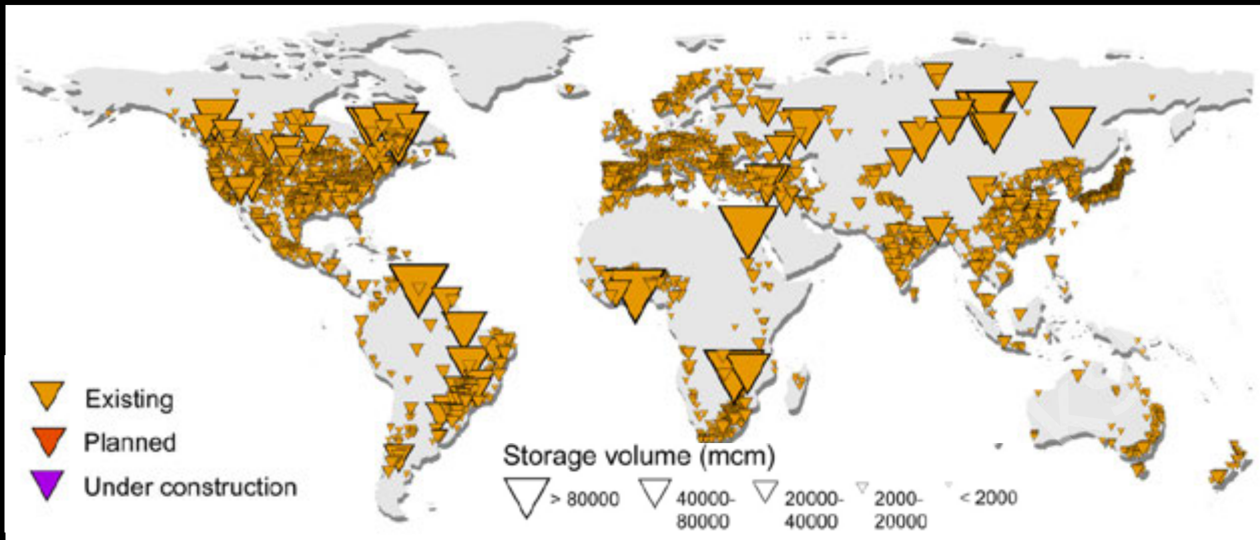


Bank erosion (permafrost thaw) along tributary of Colvile River

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

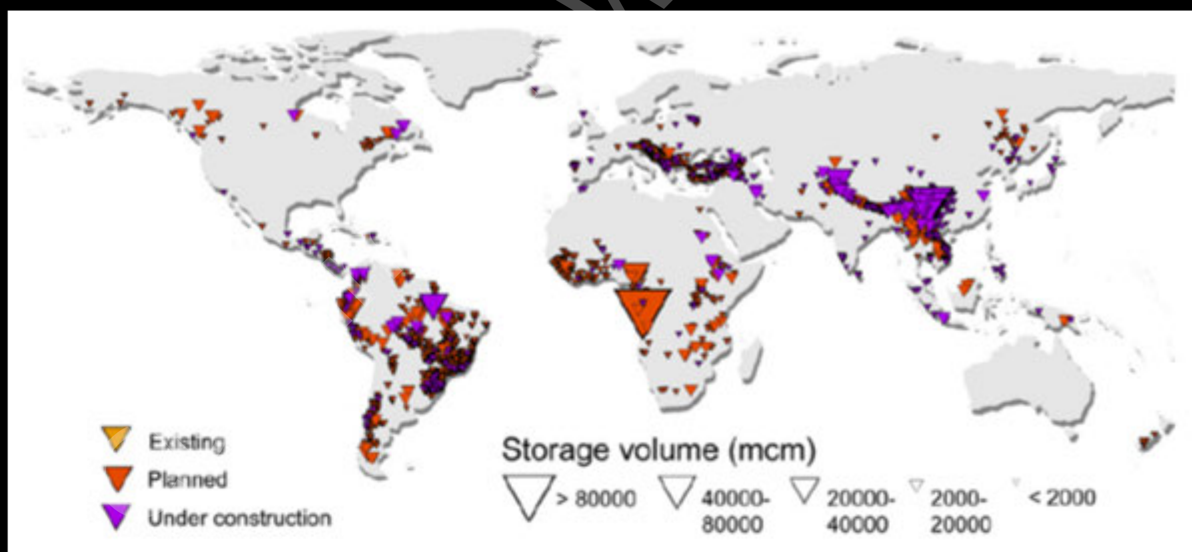
The Bianchi Lab

Dams and the Coastal Margin



Existing Dams in the World

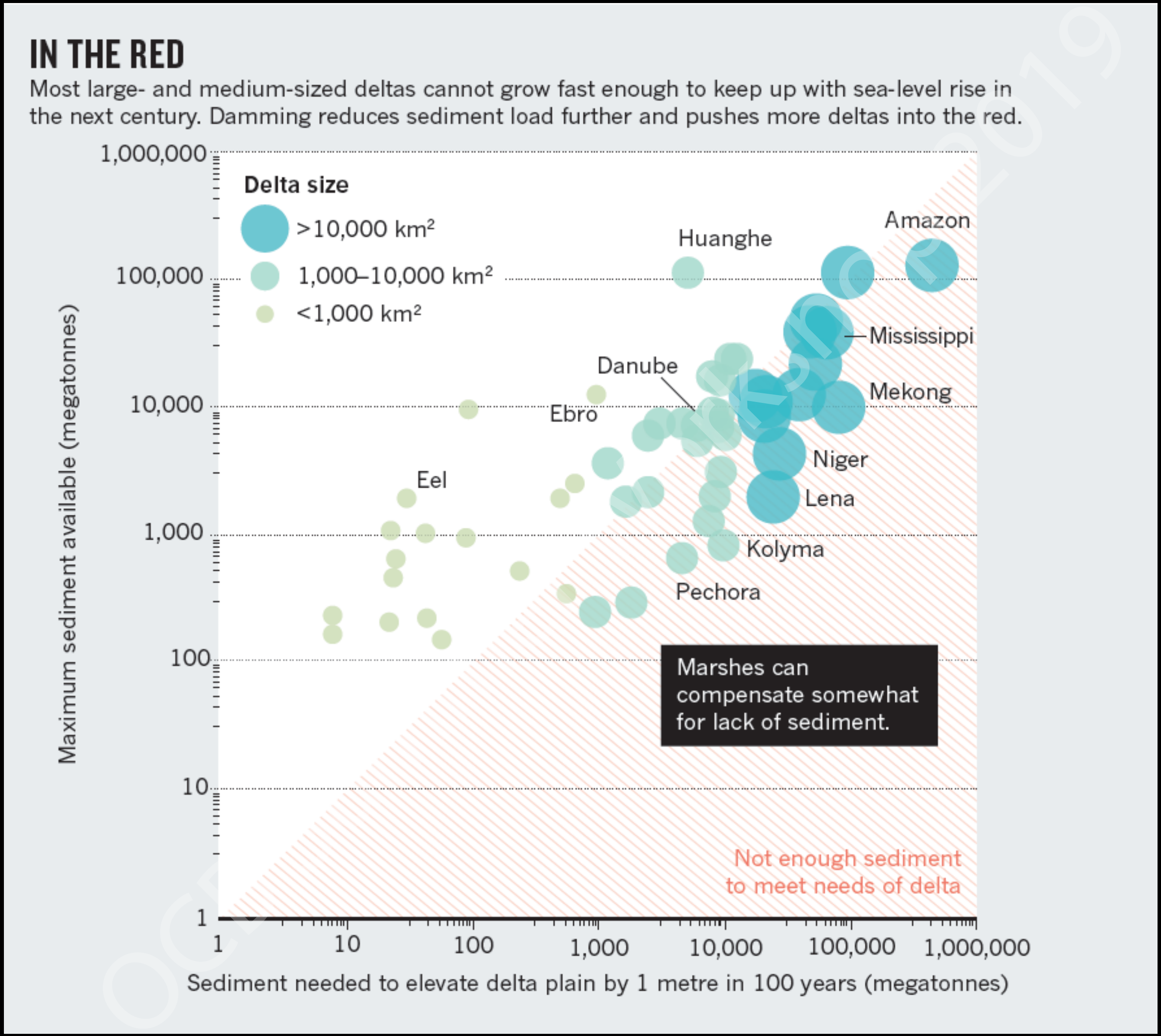
Dams Under Construction or Planned



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

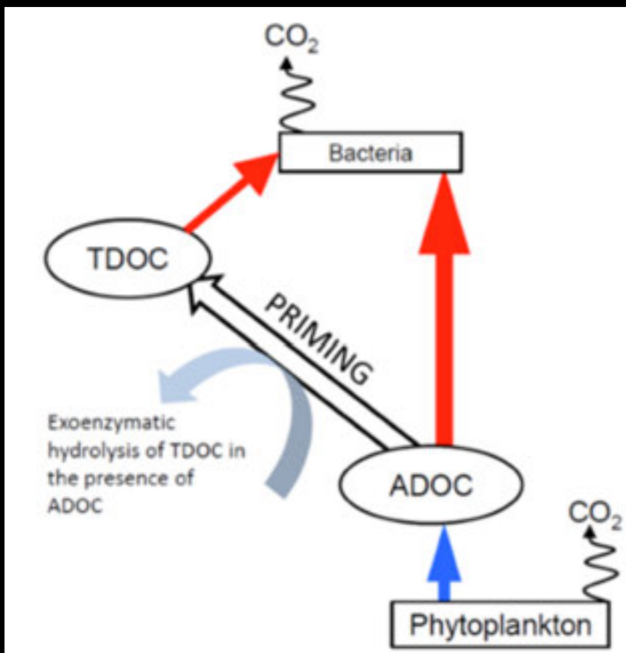
The Bianchi Lab

The Loss of Coastal Deltas

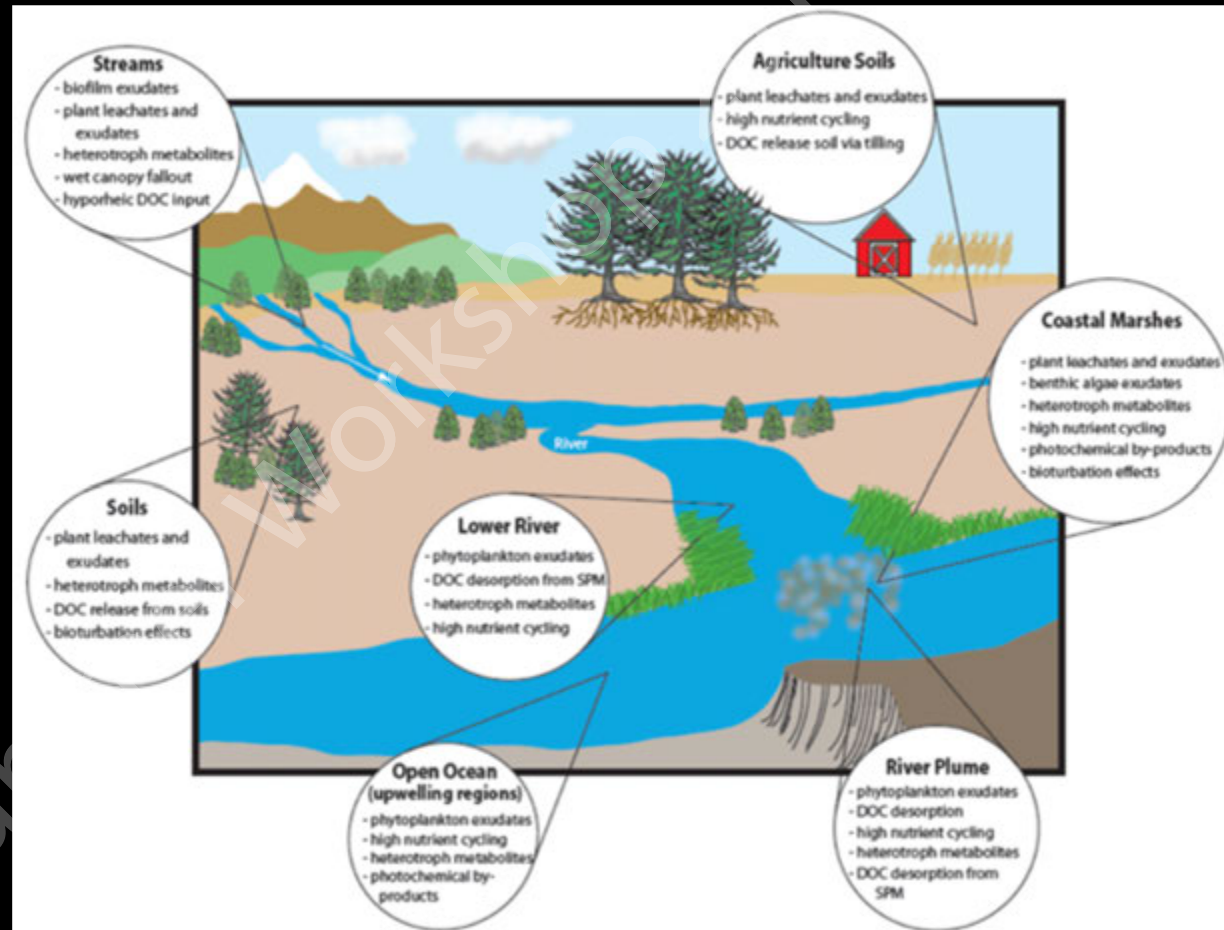


Giosan et al. (2014) *Nature*

Priming in the Aquatic Continuum



Bianchi et al. (2015) *GRL*



Bianchi (2011) *PNAS*

Recent evidence for priming in aquatic systems: Guenet et al. (2014) *Ecol.;* Bianchi et al. (2015) *GRL;* Ward, Bianchi et al. (2017) *JGR*

The Bianchi Lab

Possible "Hot Spots" for Priming in the Aquatic Continuum

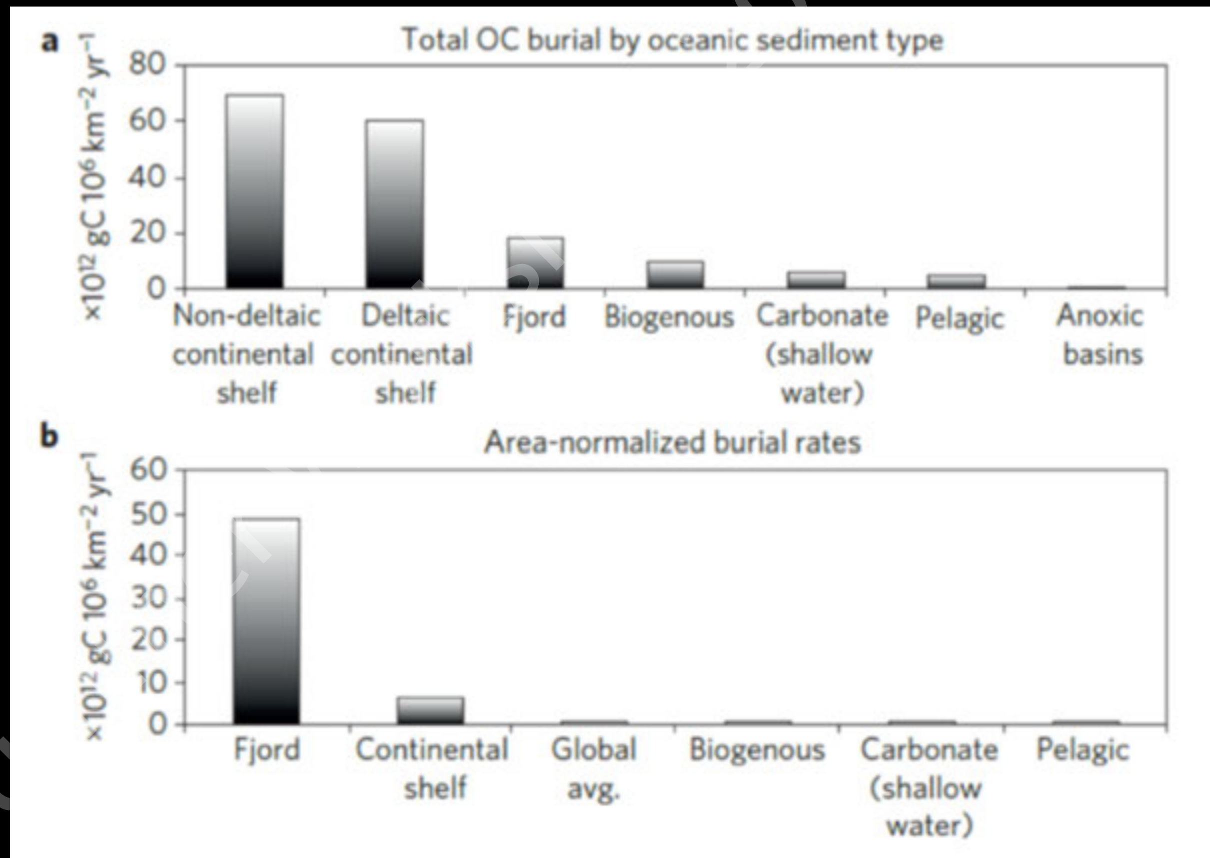
Reservoirs

River Confluences

River Plumes

The Bianchi Lab

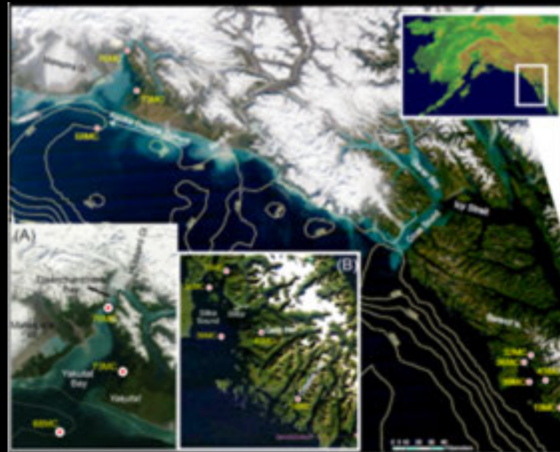
Organic Carbon Burial in Fjords and Ocean Sediments

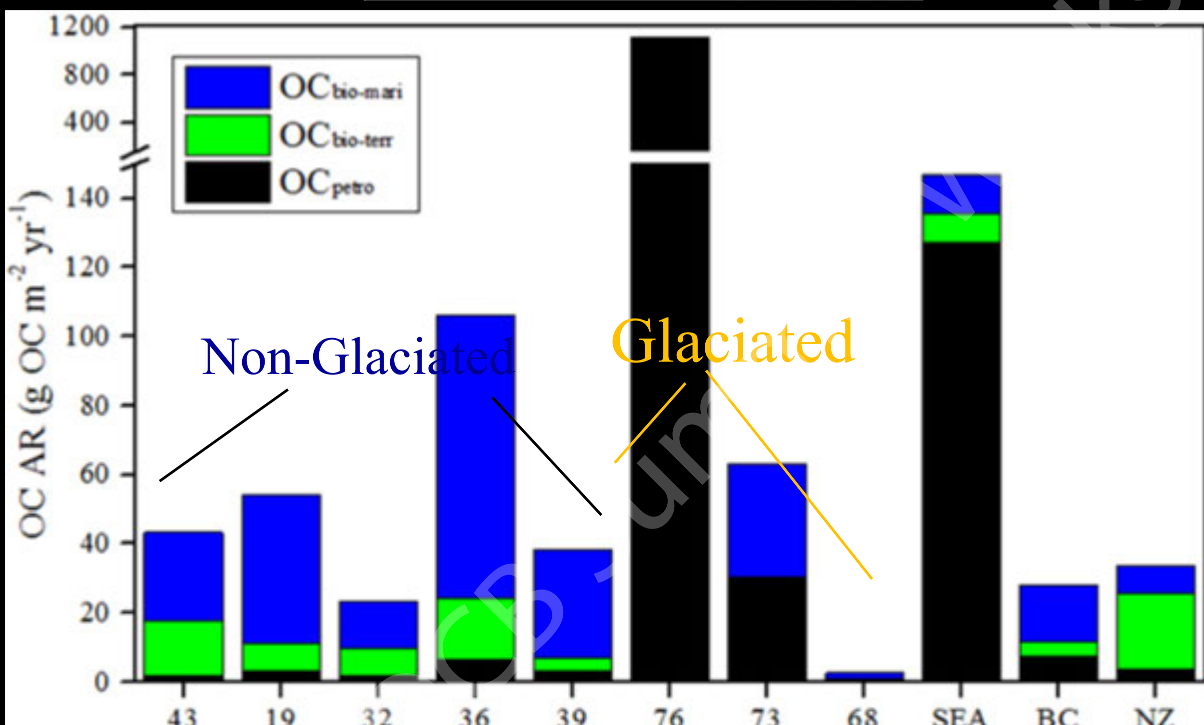


It was estimated that fjords store ca. 11% of annual marine carbon burial globally.

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

Biospheric and Petrogenic OC Flux along Southeast Alaska





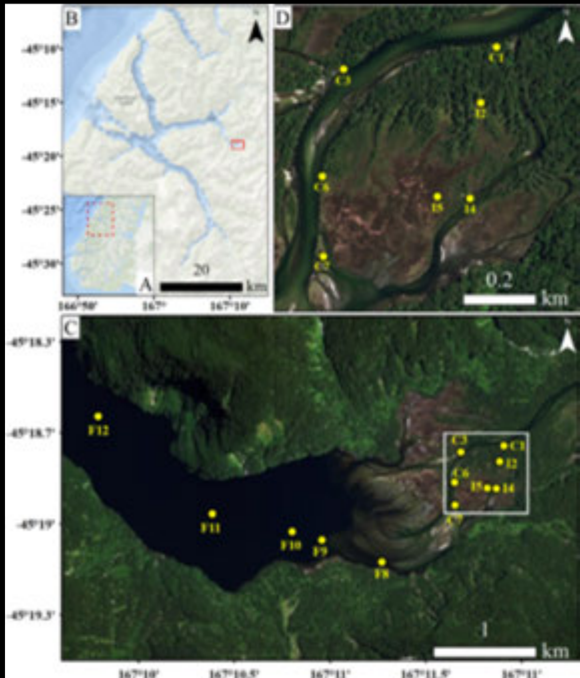
Using end-member mixing models, we determine that glaciated fjords have significantly higher burial rates of OCpetro (1113 g OC m-2 yr-1).

In contrast, non-glaciated fjords in SE Alaska are effective in burying marine OC (OCbio-mari) (13 - 82 g OC m-2 yr-1).

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

The Bianchi Lab

High OC "Burn down" in ACZ



Camelot River connects with relict Gaer Arm delta, which formed during deglaciation fca. 17 to 14 ky BP.

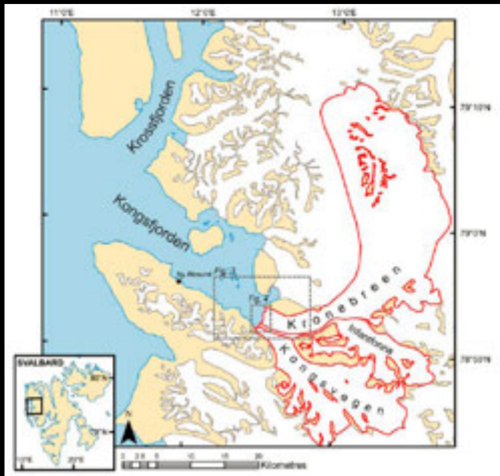
High processing of OC in coarse-grained sediments

Significantly higher acid/aldehyde ratios of vanillic phenols [(Ad/Al)v] at the deltaic stations (0.45–0.82) than in fjord sediments from deeper waters (0.29-0.40).

Cui, Bianchi et al. (2018) *JGR-Biogeo.*

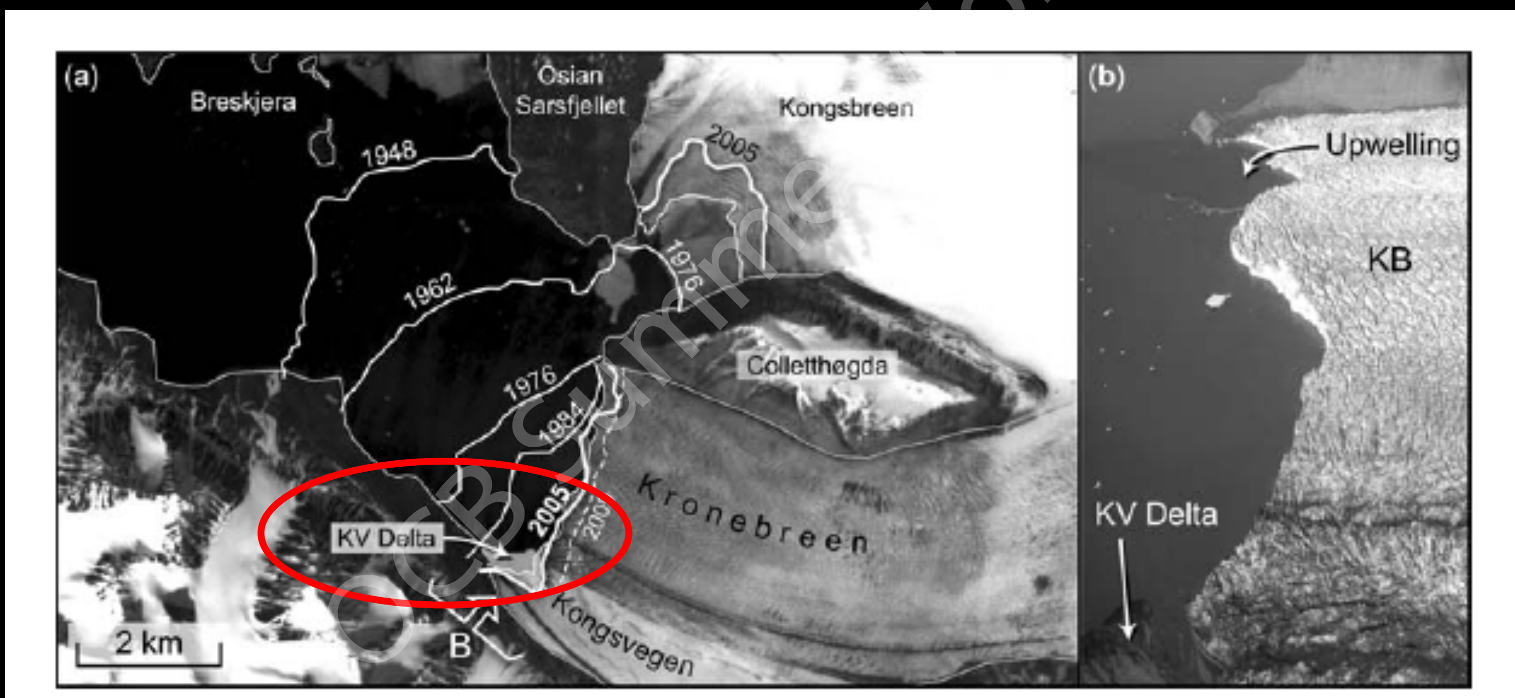
The Bianchi Lab

New Platforms for Rapid Cycling of OC and Fe inputs?



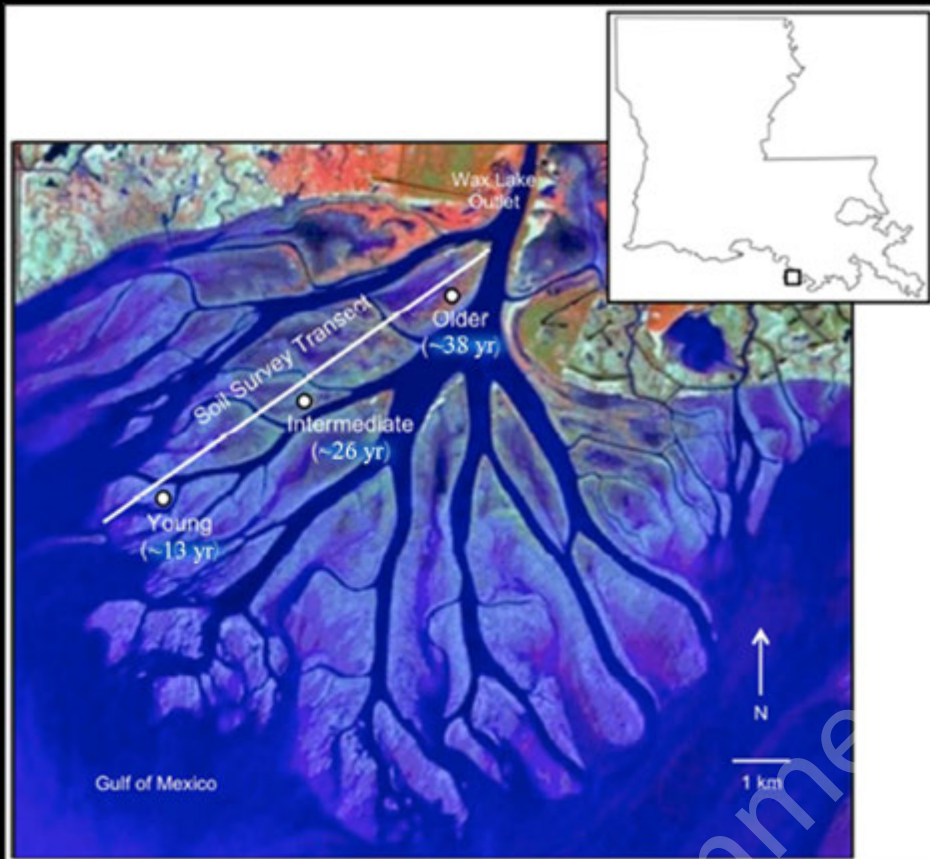
Retreating glaciers in Svalbard, Norway, allow for new delta platforms to form; potential for rapid OC processing in oxidized coarse-grained deltaic sediments.

Greater phytodetrital inputs to sediments, post-retreat from glacier melt which is high in Fe, e.g., Hopwood et al. (2016) *Front. Mar. Sci.*



Trusel et al. (2010) *Geol Soc.Lon.*

Carbon Burial in an Embryonic Delta

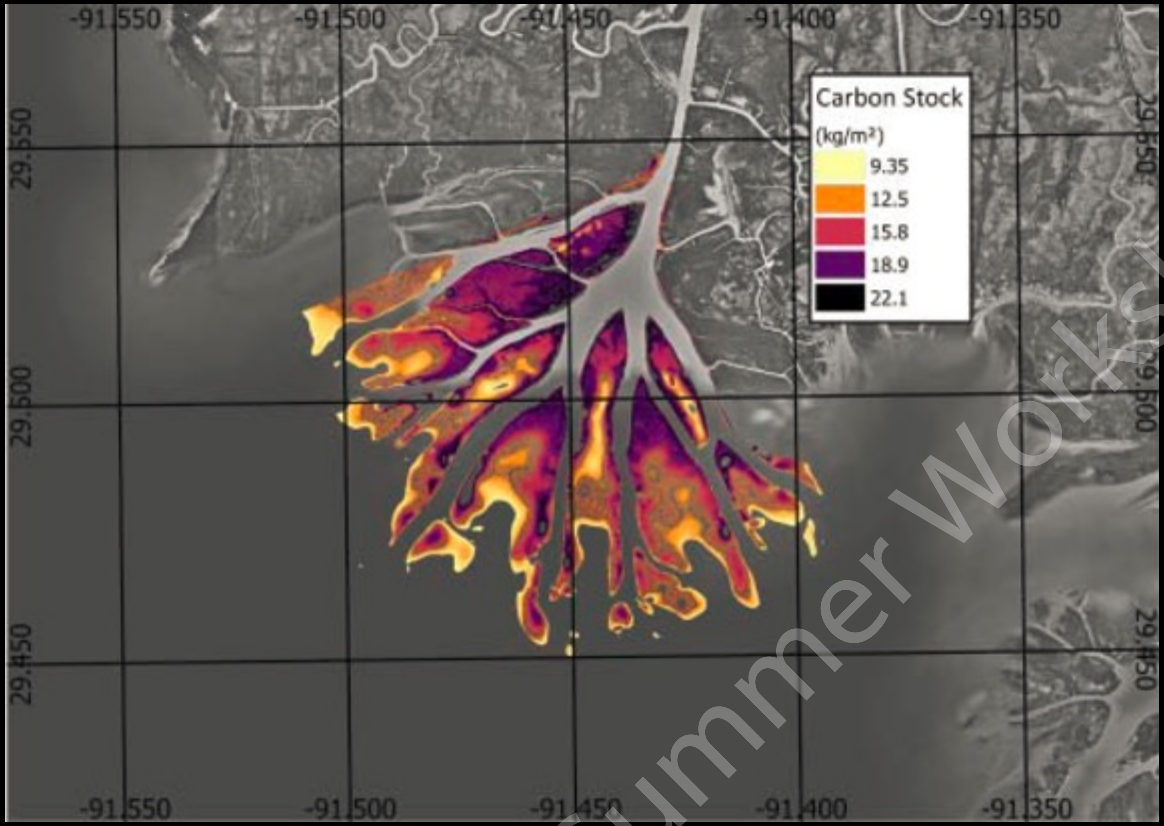


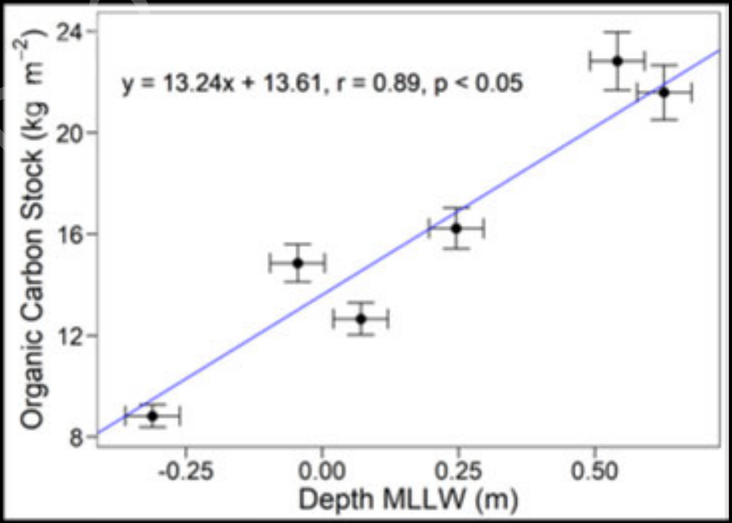
This delta formed as a result of the construction of the **Wax Lake** outlet in 1941. The outlet was built to provide flood relief for the lower Atchafalaya River.

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

The Bianchi Lab

Carbon Stock and Elevation





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

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

The Bianchi Lab

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.

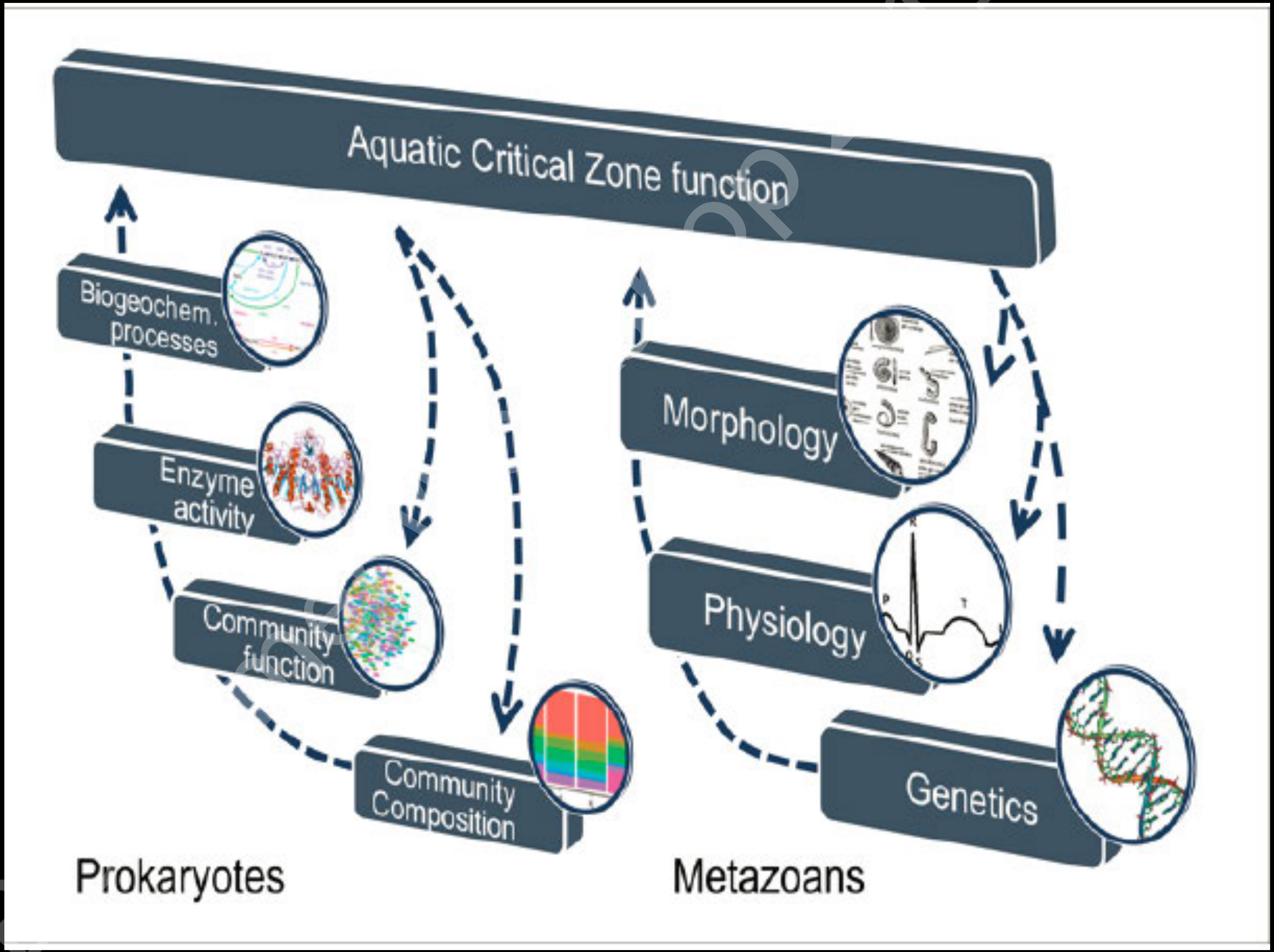
Shields, Bianchi et al., (2016) *Geophys. Res. Lett.*

The Bianchi Lab

Macrobenthos on the Move in Aquatic Critical Zones: Implications for Carbon Storage

Aquatic Critical Zones

How do changes in flooding events, storms, species invasions, river diversions, HABs, hypoxia, damming, etc. etc. impact adaptation by metazoan communities in ACZs?



Bianchi and Morrison (2018) *EOS*

The Bianchi Lab

Macrobenthos and Global Sediment Carbon Cycling

Strong spatial variability in carbon burial and recycling rates of organic material may relate to recognized variation in seafloor functional group composition.

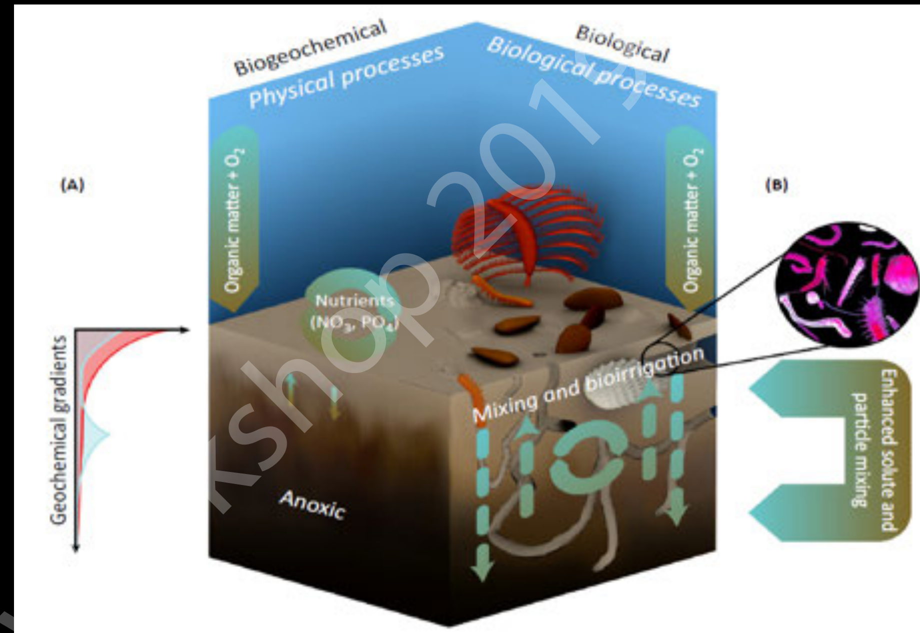


Table 1. Global Average Estimates of Sedimentary Processing of Organic Carbon in Terms of Sediment Community Oxygen Consumption (SCOC), Production of Dissolved Inorganic Carbon (DIC), and Biological Turnover[a]

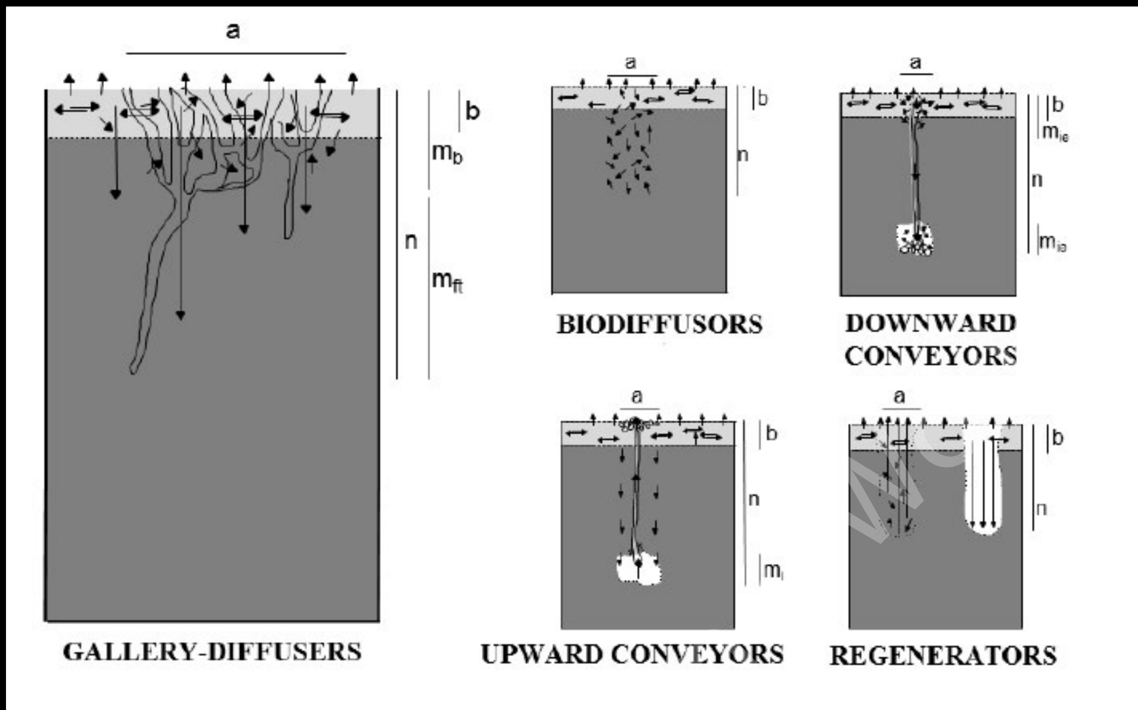
Source	SCOC (Tmol O2·yr^{-1})	DIC (Gton C·yr^{-1})	Biological turnover (yr^{-1})	Biological turnover (day^{-1})
[63]	54.3	0.65	7.7	0.02
[64]	79.6	0.96	11.3	0.03
[65]	157	1.88	22.2	0.06
[11]	152	1.82	21.5	0.06
Our study	139.5	1.67	19.7	0.05

[a]Based on a respiratory quotient (DIC:O_2 exchange ratio) of 1.0 and a total seafloor biomass of 84.9 megaton C [56].

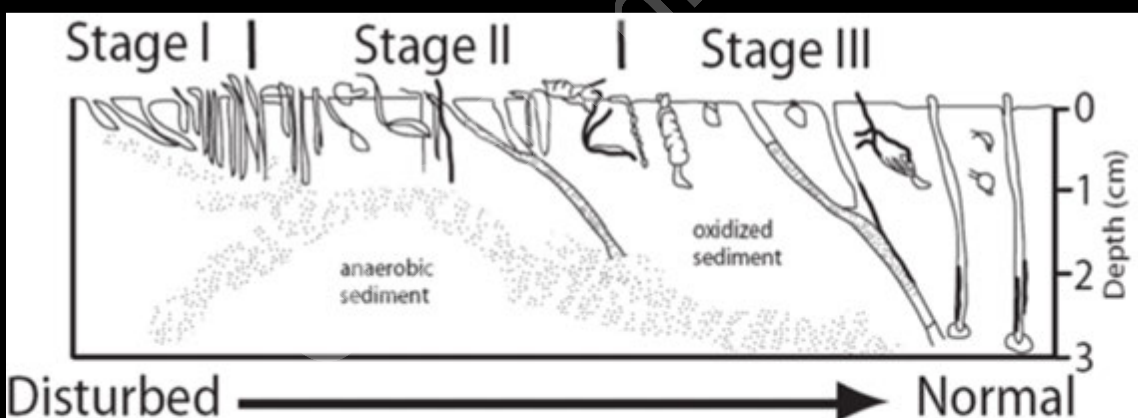
Snelgrove et al. (2017) *Trends Ecol. Evol.*

The Bianchi Lab

How Might Changes in Macrofaunal Functional Feeding Groups in ACZs (and beyond) Impact Carbon Burial?

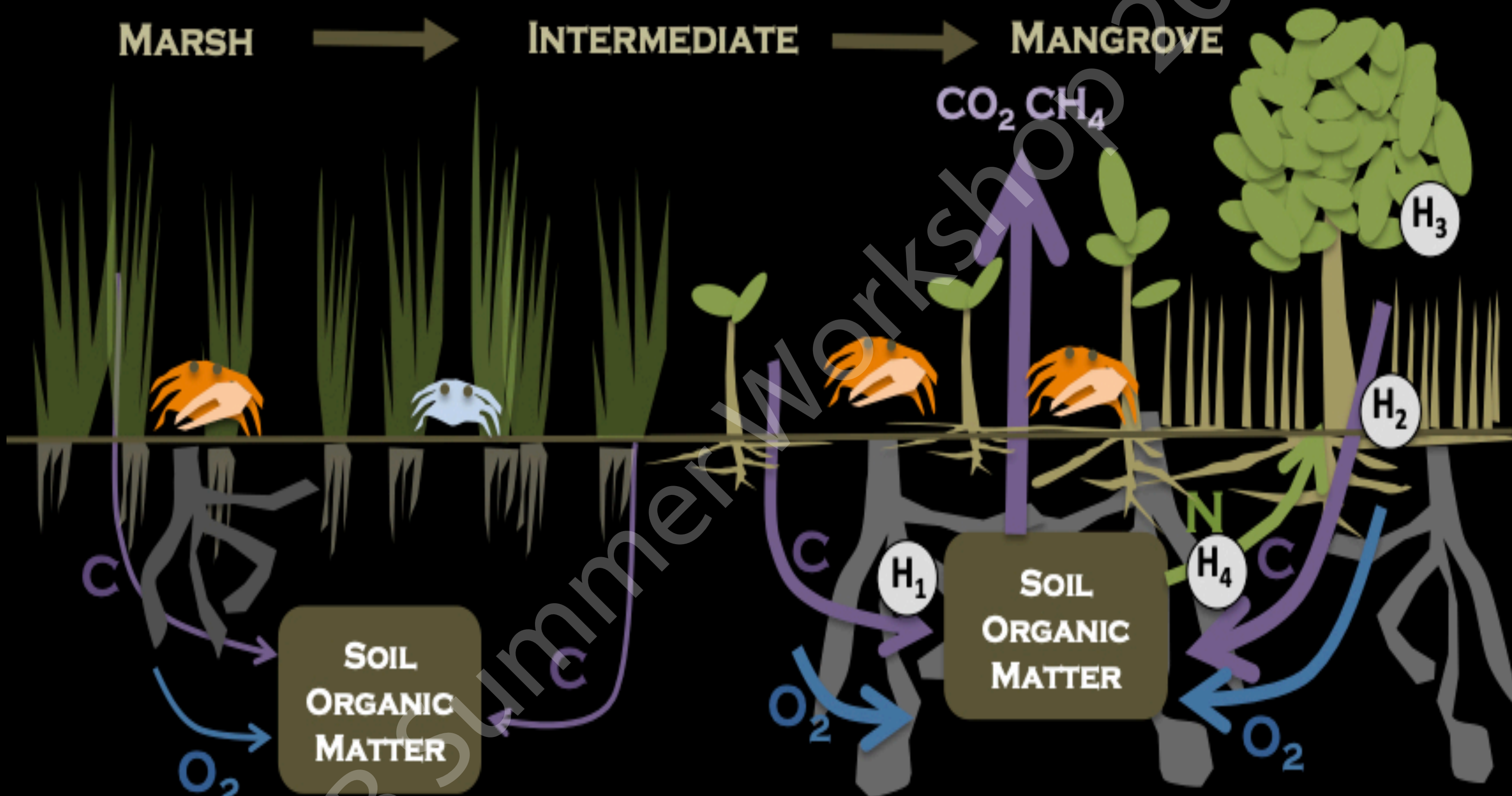


Francois et al. (2001) *Comp. Rend. Acad. Sci. III-Vie*



Zajac (2001) *In: Woodin, S.A., Aller, R.C. (Eds.), Organism – Sediment Interactions. University of South Carolina Press, Columbia.*

Macrofaunal Changes with Foundational Plant Species Migration



Bianchi et al., *unpublished*

Final Thoughts

1. More studies needed in soil/sediment carbon dynamics with changing benthic fauna and mixing rates, due to animal poleward migration from tropicalization, with evolutionary adaptive and phenotyic plasticity.

2. Changes in bioturbation from changing benthic community composition should have an impact (increase or decreases) on carbon storage in ocean sediments via changes in redox, particle/aggregate size, and mixing rates.

3. Zones of deglaciation will change the residence time, processing time, and age of terrestrially-derived organic carbon inputs to coastal sediments, thereby changing carbon burial rates.

4. Changes in the water flow in aquatic continuum, in part from dams, regional changes in precipitation, will alter total suspended particulates, nutrient fluxes, coastal geomorphology etc.. These changes will alter rates of organic carbon turnover (via microbial and photochemical processing) and allow for priming in newly created aquatic critical zones (e.g., coastal river plumes, dam reserviors, river confluences).

Animal-Sediment Interactions – Biogeochemical Consequences in the 21st Century

T.S. Bianchi, R.C. Aller, T. Atwood, L.A. Buatois, L.A. evin, J.S. Levinton,, J.J. Middelburg, E.S. Morrison, P. Regnier, M.R. Shields, P.V.R. Snelgrove E.E. Sotka, and R.R.E. Stanley

For: Nature Reviews Earth & Environment (in Prep)

Evolution of Global Ocean Carbon Burial

Organic carbon burial rates in various ocean sediments (unit, 10^{12} g C 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/∑OM$_{bur}$[a]	Burial Rate[b] ∑OM[c]	Burial Rate[b] TOM[d]	TOM Burial (% of ∑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]. ∑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^{-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 burial (Tg C yr^{-1}) 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.*