CCARB Workshop
Woods Hole , Aug 2014

Burial & Sediment/Water Exchange

Miguel Goñi
College of Earth, Ocean & Atmospheric Sciences
Oregon State University

Extent of knowledge of burial/sediment exchange along North American Margin

Global budgets

➔ Importance of ***Ocean Margins***

Budgets from GMEX report

Budget from East Coast report

Budget from West Coast (Alin et al., 2012)

Budgets from Arctic margins (Stein & Macdonald, 2004)

Global Organic Carbon Sources

Organic Carbon Sources	Inputs (10^6 t/y)
Marine Primary Production	30,000-50,000
River Input (POC)	130-150
River Input (DOC)	210-230
River Input (TOC)	330-430
Eolian Input	100-320

Global Organic Carbon Burial

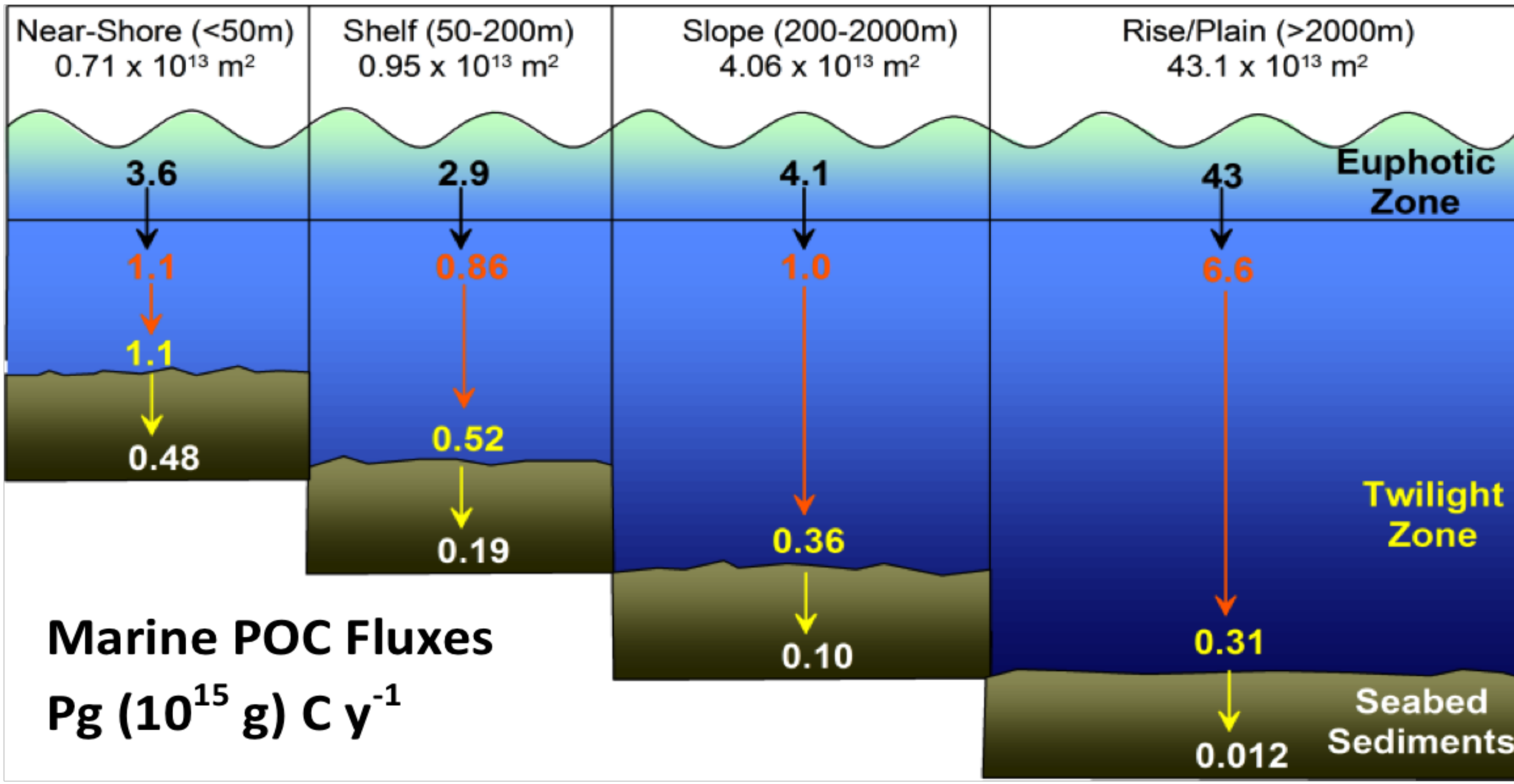
Organic Carbon Sediment Sink	Sediment Burial (10^6 t/y)
Deltaic sediments	70
Shelves & upper slopes	68
High-Prod. Zones	10
Shallow carbonates	6
Pelagic sediments	5
Anoxic basins	1

Burial ~ 0.4% of Total Inputs

Stein & Macdonald, 2004

Carbon Fluxes in Different Ocean Regimes
Dunne et al., 2007

Regionally variable



Regional Contrasts in Ocean Sediment Carbon Sink (Dunne et al., 2007

	Near-shore	Shelf	Slope	Rise/Plain
%Area =	2.0%	2.7%	6.4%	89%
%PP =	6.7%	5.4%	7.5%	80%
%Seabed Accum =	48%	23%	16%	13%
%Burial =	**61%**	**24%**	**13%**	2%
Burial Efficiency = (Accum/Burial)	**44%**	**37%**	**28%**	3.9%
Net Carbon Storage = (Burial/NPP)	**13%**	**6.6%**	**2.4%**	0.028%

Margins play a key role!

High Burial Efficiencies and Net Carbon Storage Rates!

Jahnke – Chapter 16 Global Synthesis
Liu et al., 2011

Table 16.4.4 Summary of primary production, air–sea exchange and slope and rise organic carbon deposition by major ecosystem type

Ecosystem type	Total primary production g C yr^{-1} ($\times 10^{12}$)	Total air–sea exchange mol CO_2 yr^{-1} ($\times 10^{12}$)		Total slope and rise deposition mol OC yr^{-1} ($\times 10^{12}$)
Polar	644	13.02		3.20
Sub-polar	2,396	18.88		2.02
Western boundary current	1,937	−6.36		1.78
Eastern boundary current	2,751	1.43		3.63
Tropical	1,136	−0.22		2.63
Monsoonal	2,230	−2.61		2.33
Shelf-dominated	4,976	19.20	≈	5.70
Slope-dominated	6,118	4.94		9.90
Total	11,094	24.14		15.59

Sediment Sink in slope/rise same order of magnitude as CO_2 air/sea Exchange

Burial/sediment exchange along North American Margin

Global budgets – focus on ***Ocean Margins***

➔Budgets from GMEX report
➔Budget from East Coast report
➔Budget from West Coast (Alin et al., 2012)
➔Budgets from Arctic margins (Stein & Macdonald, 2004)

Gulf of Mexico Budget (Tg C yr^{-1})

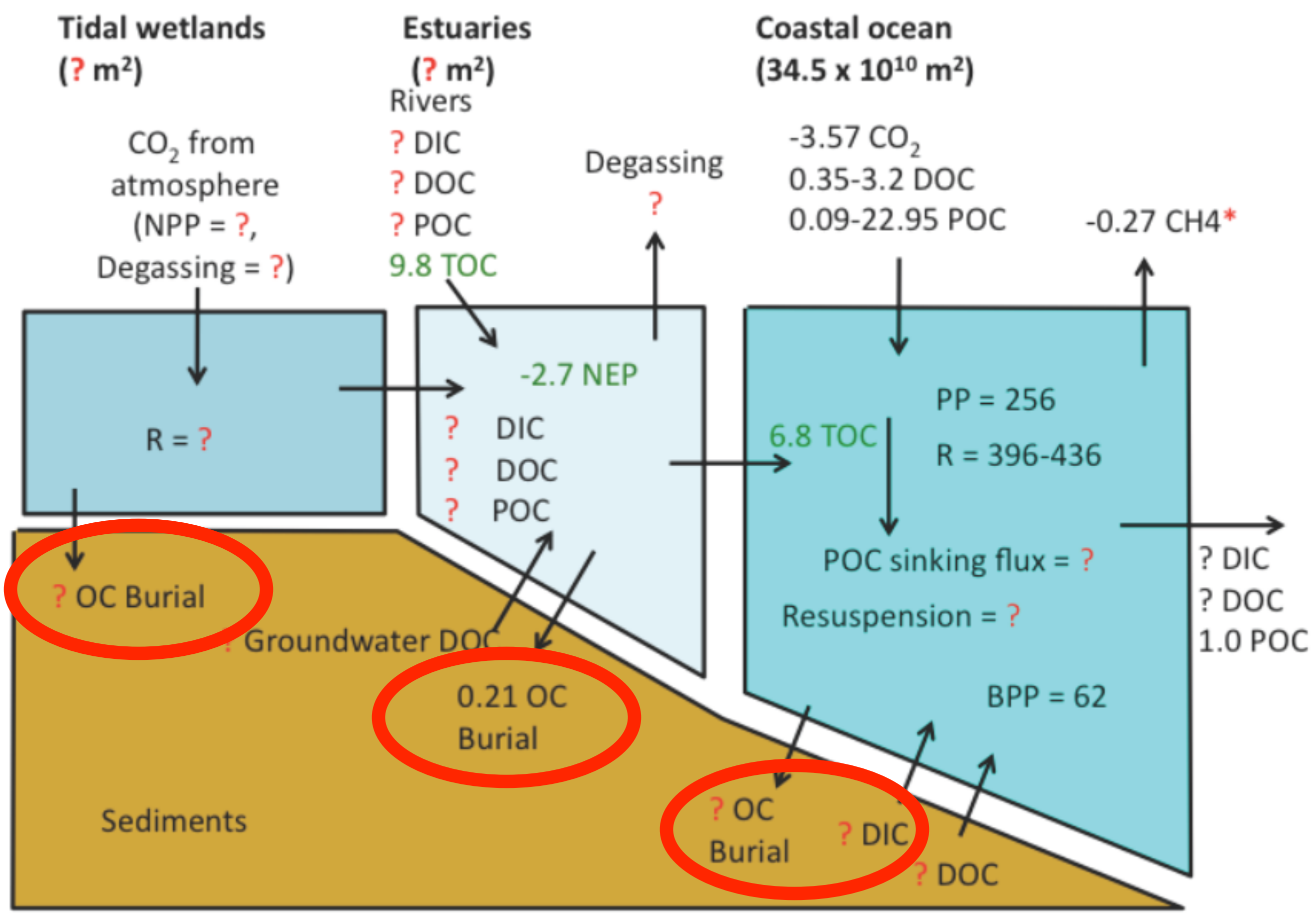


Figure 8.1. Updated carbon budget for the Gulf of Mexico based on synthesis a conducted in preparation for the workshop and shortly thereafter. R = respiration, OC = carbon, POC = particulate organic carbon, DOC = dissolved organic carbon, DIC = d inorganic carbon, PP = primary production, BPP = benthic primary production, NE ecosystem production.

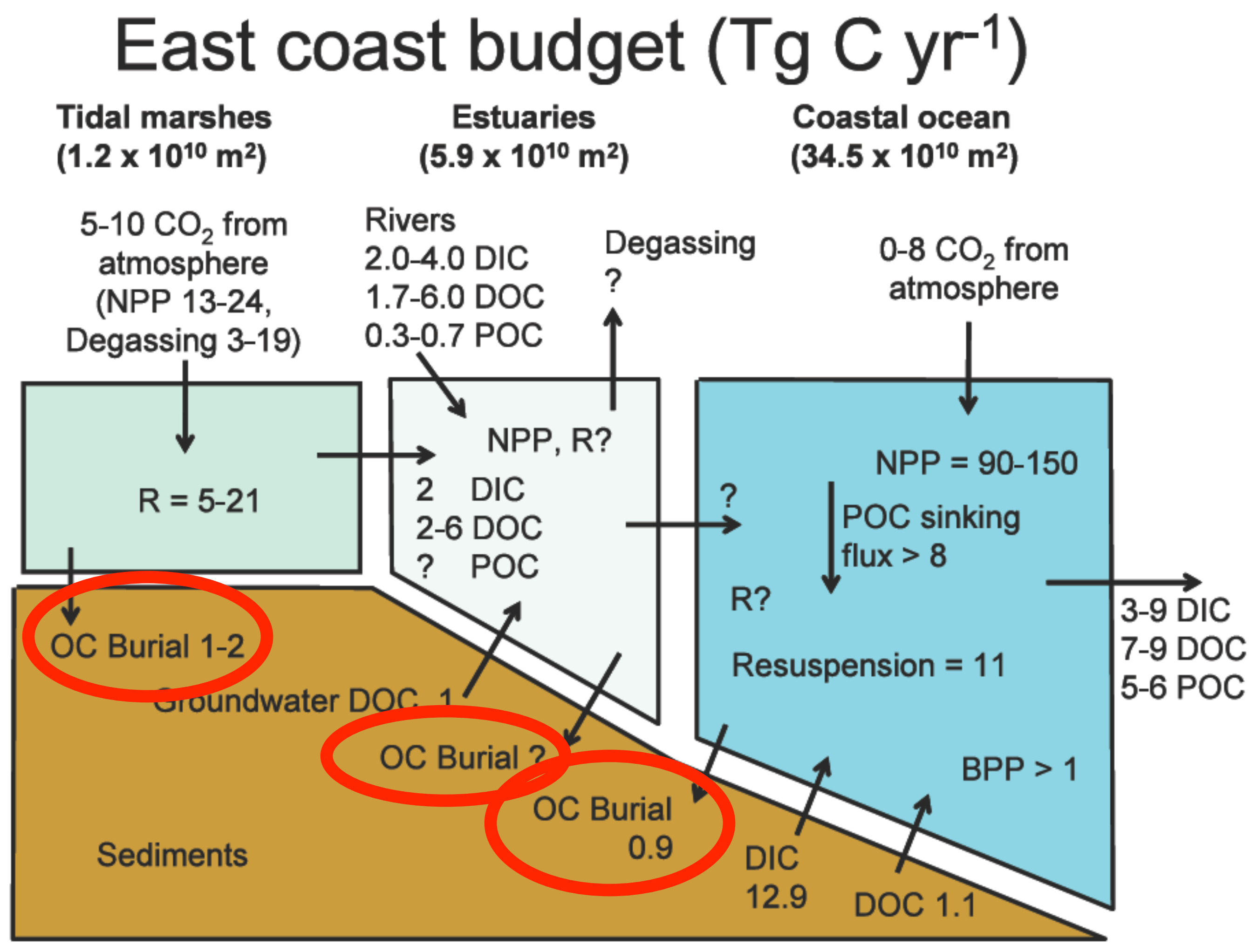
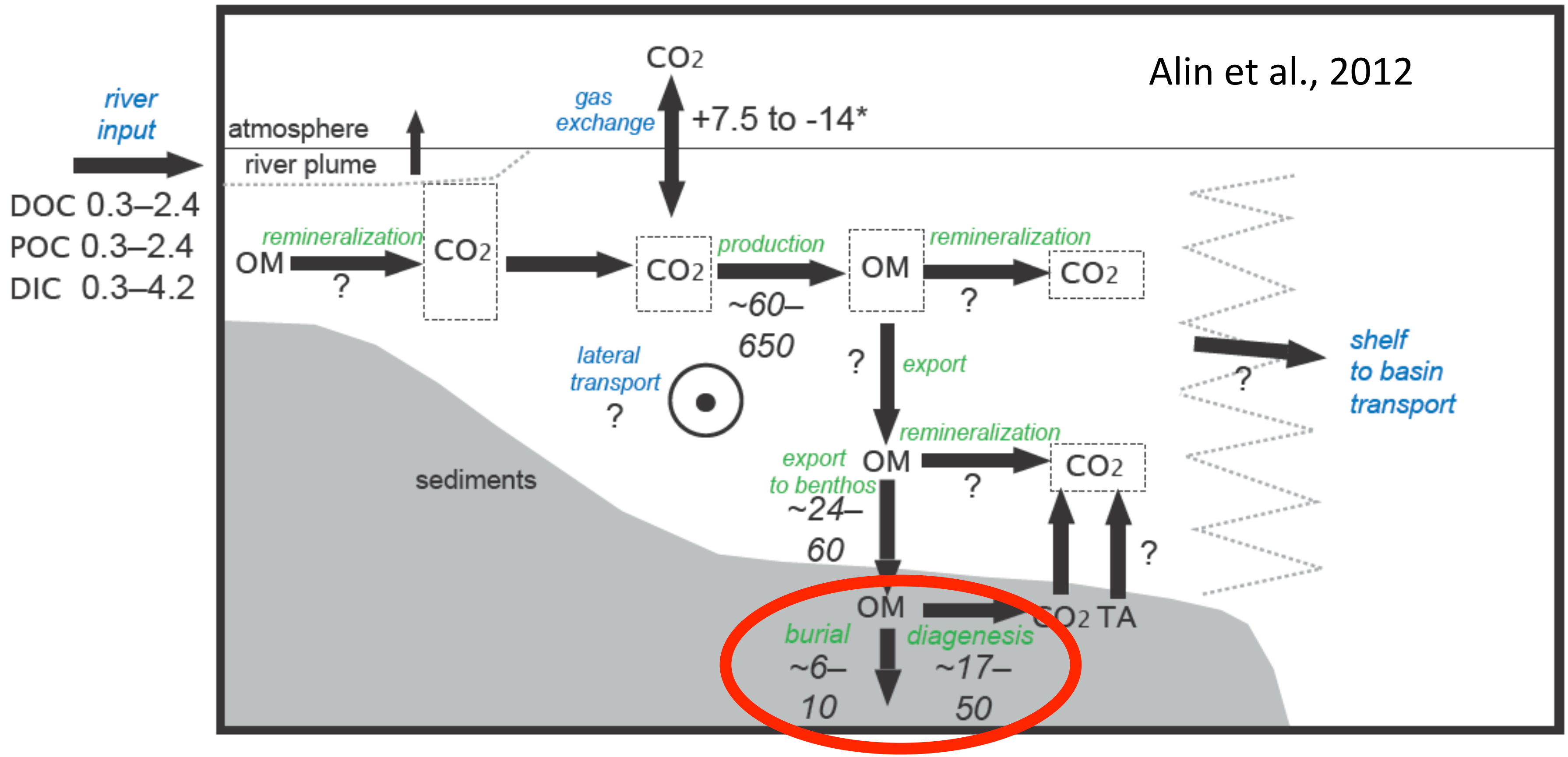
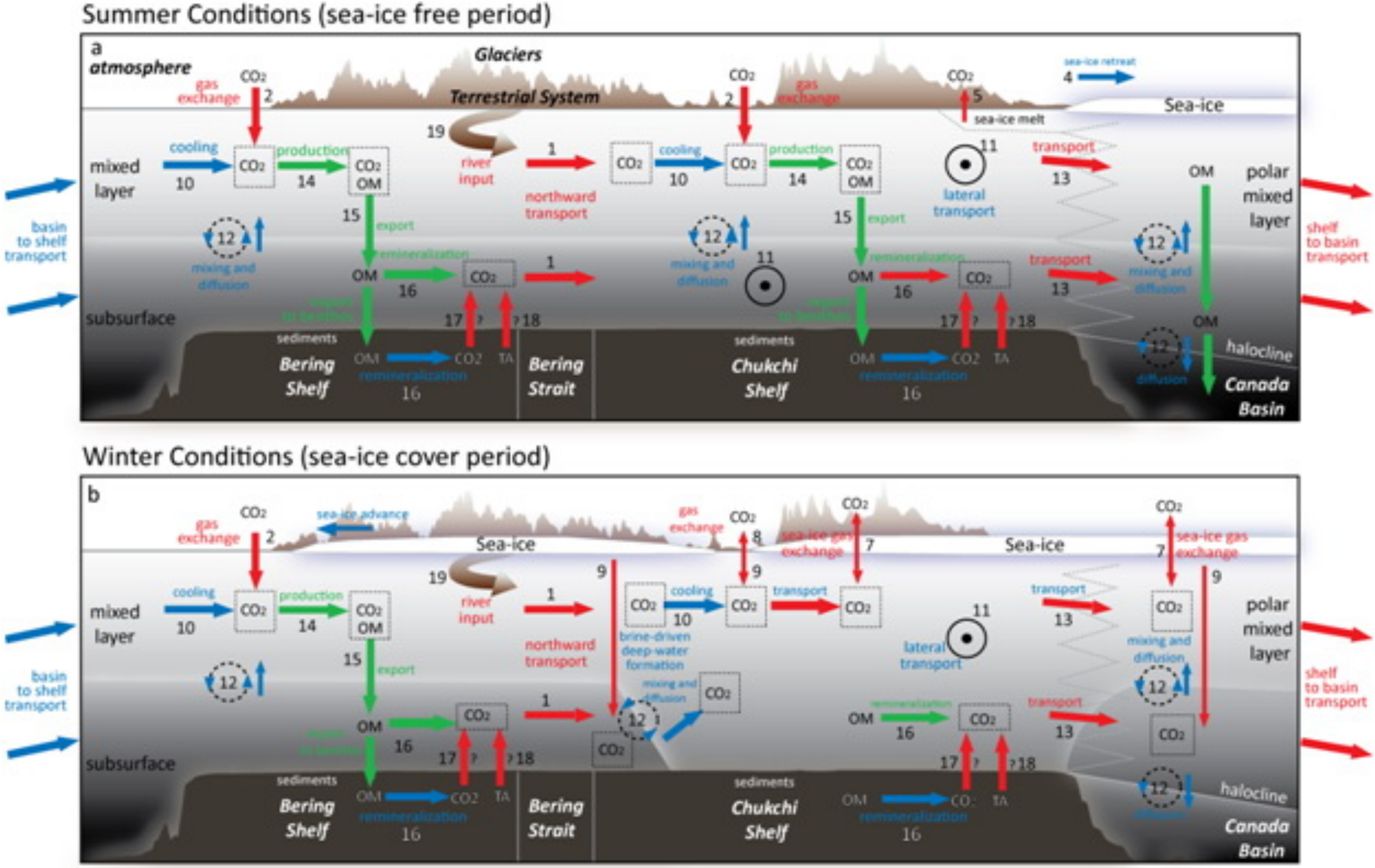


Fig. 6. Preliminary carbon budget for the coastal zone of the eastern U.S. based on synthesis activities conducted in preparation for the workshop and shortly thereafter. R = respiration, OC = organic carbon, BPP = Benthic primary production.

Coastal Carbon Synthesis for the Continental Shelf - West Coast



Bering Sea, Chukchi Sea and Canada Basin carbon cycle schematic



The Extent and Controls on Ocean Acidification in the Western Arctic Ocean and Adjacent Continental Shelf Seas

J. T. Mathis, 2011. http://www.arctic.noaa.gov/report11/ocean_acidification.html

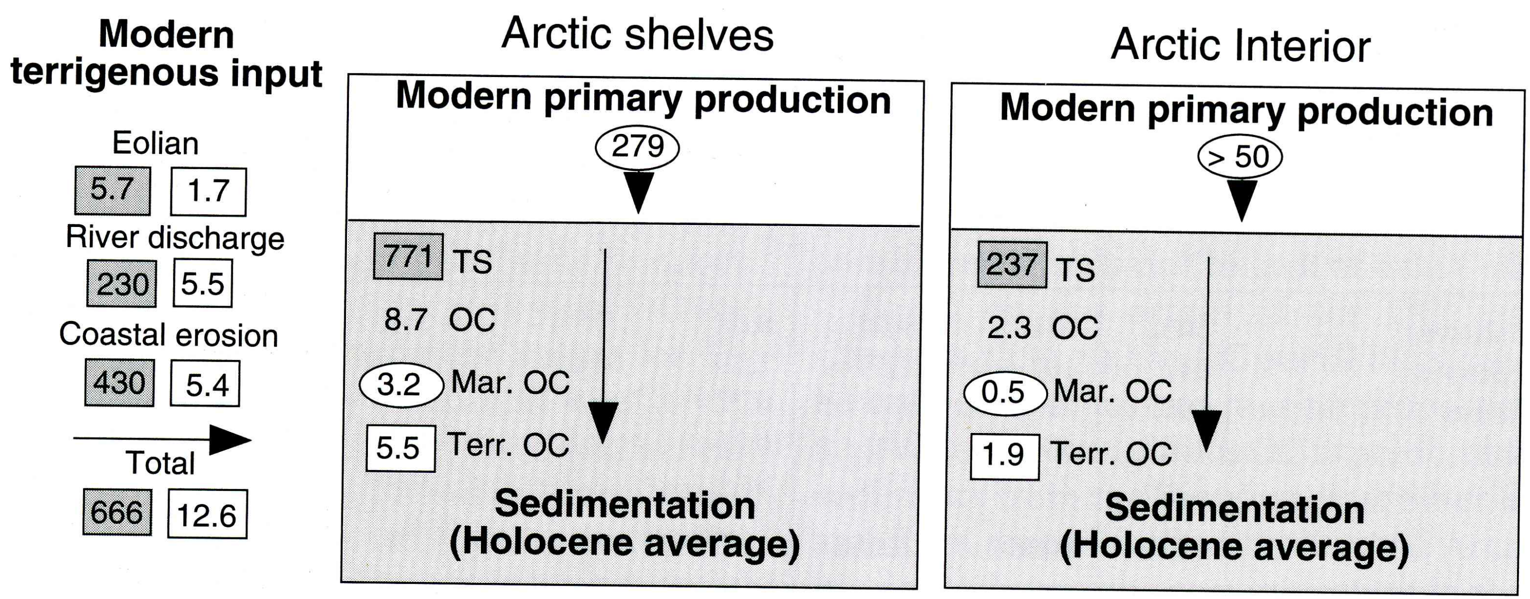
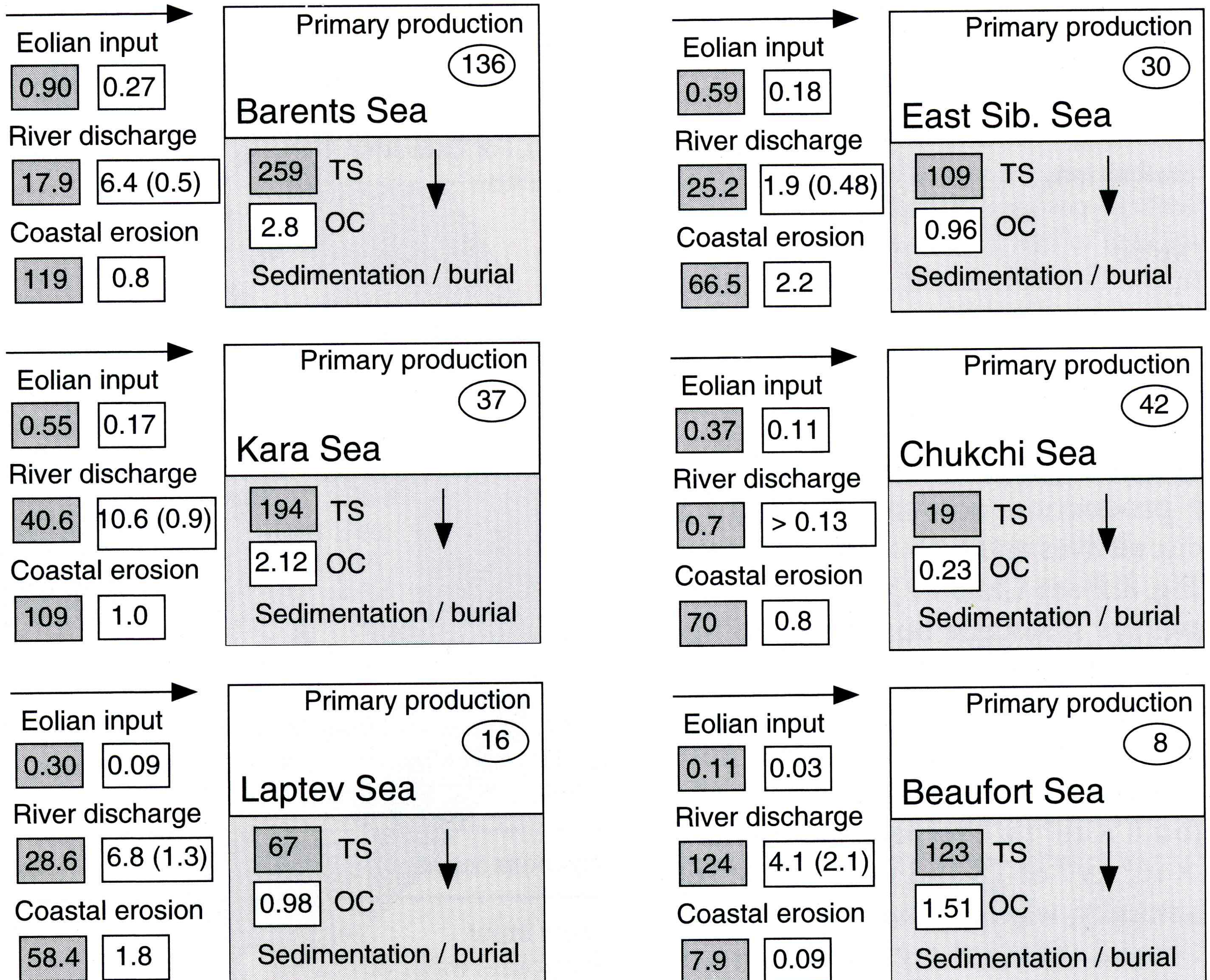


Fig. 8.4. Summary for modern terrigenous sediment and particulate OC and marine OC (primary production) input and average Holocene burial rates for the Arctic shelves and interior basins. All numbers in 10^6 t y^{-1}. Note the mismatch between total sediment input and total sediment accumulation. For data source and references see Table 8.3

Stein, R. and Macdonald, R.W. (Editors), 2004. The Arctic Ocean Organic Carbon Cycle: Present and Past. Springer, Berlin-Heidelberg-New York.


Eolian input
0.90
0.27
River discharge
17.9
6.4 (0.5)
Coastal erosion
119
0.8
Primary production
136
Barents Sea
259
TS
2.8
OC
Sedimentation / burial
Eolian input
0.59
0.18
River discharge
25.2
1.9 (0.48)
Coastal erosion
66.5
2.2
Primary production
30
East Sib. Sea
109
TS
0.96
OC
Sedimentation / burial
Eolian input
0.55
0.17
River discharge
40.6
10.6 (0.9)
Coastal erosion
109
1.0
Primary production
37
Kara Sea
194
TS
2.12
OC
Sedimentation / burial
Eolian input
0.37
0.11
River discharge
0.7
> 0.13
Coastal erosion
70
0.8
Primary production
42
Chukchi Sea
19
TS
0.23
OC
Sedimentation / burial
Eolian input
0.30
0.09
River discharge
28.6
6.8 (1.3)
Coastal erosion
58.4
1.8
Primary production
16
Laptev Sea
67
TS
0.98
OC
Sedimentation / burial
Eolian input
0.11
0.03
River discharge
124
4.1 (2.1)
Coastal erosion
7.9
0.09
Primary production
8
Beaufort Sea
123
TS
1.51
OC
Sedimentation / burial

Burial/sediment exchange along North American Margin

Global budgets – focus on ***Ocean Margins***

➔Budgets from GMEX report

➔Budget from East Coast report

➔Budget from West Coast (Alin et al., 2012)

➔Budgets from Arctic margins (Stein & Macdonald, 2004)

Key observations :

One of the most poorly constrained terms in these budgets

➔A lot of question marks

Magnitude of the terms appear sizeable relative to other net fluxes

➔ Likely a significant term along shelf, slope & rise!

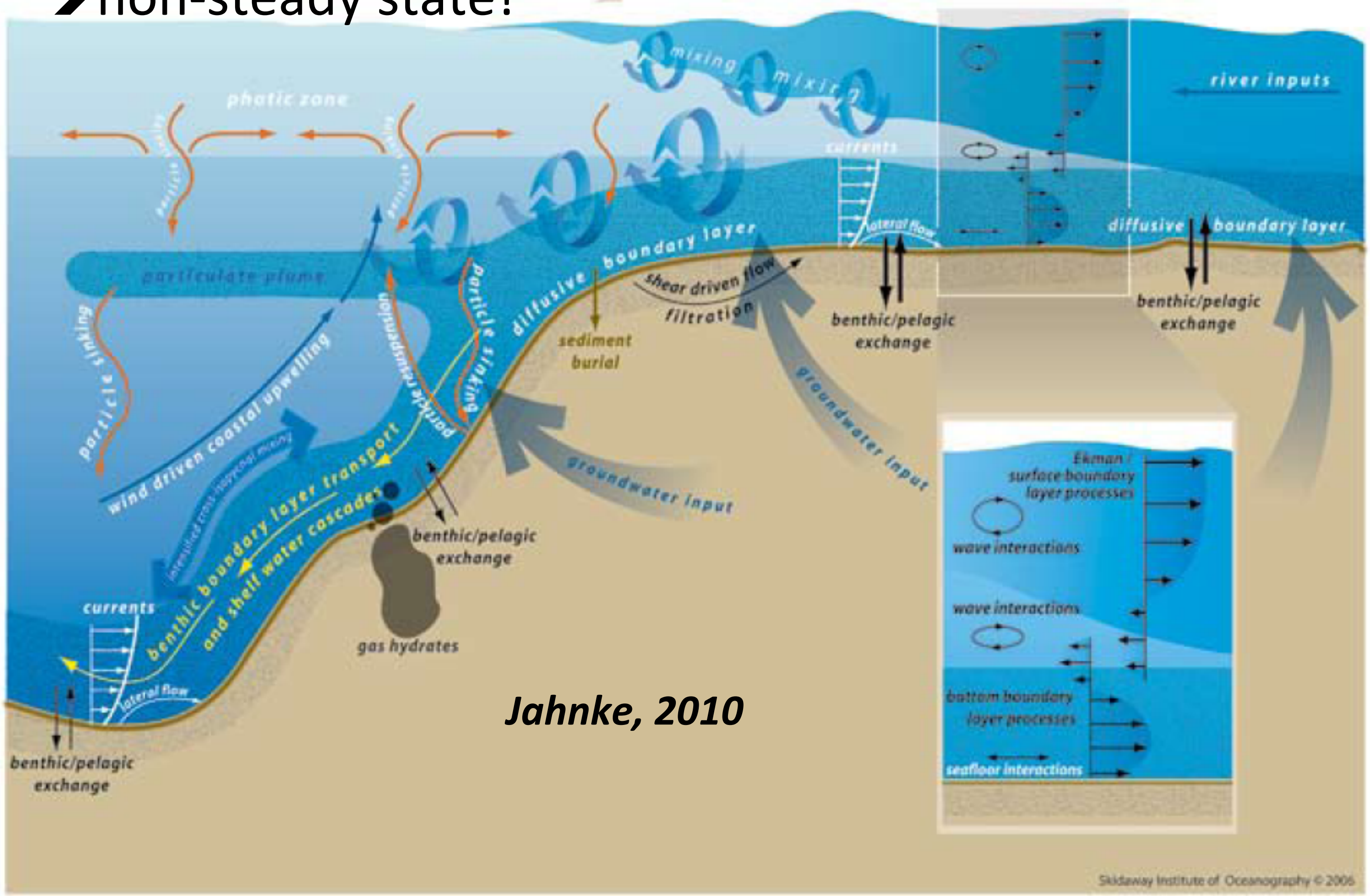
Why such poorly constrained burial/sediment exchange flux terms?

1) Poor spatial (temporal) coverage (both rates & concentrations)
2) Issue of timescale of measurements
3) Issue of spatial scale of measurements

Carbon burial and sediment exchange in continental margins

Extremely dynamic systems

➔non-steady state!



Jahnke, 2010

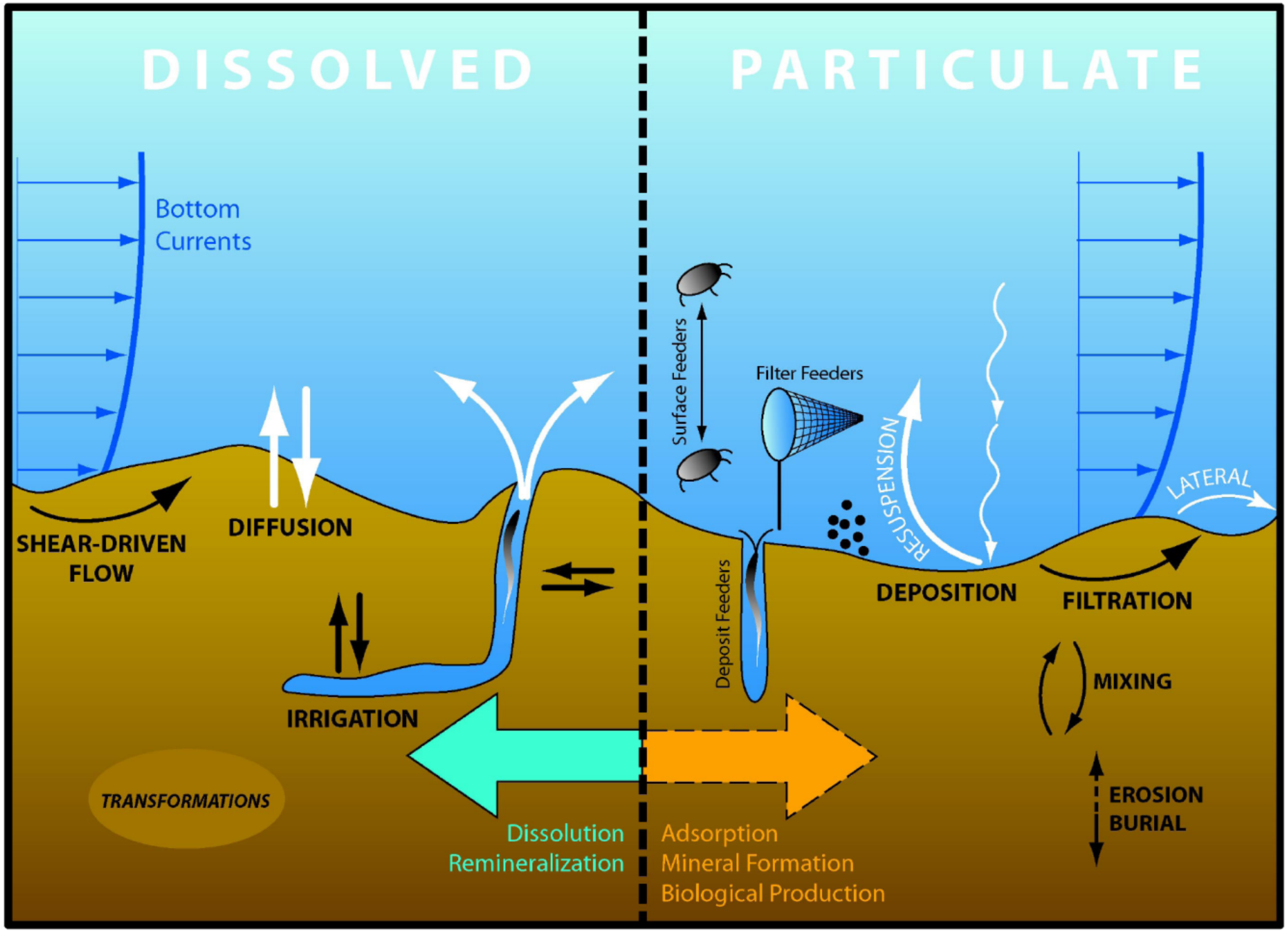
Liu et al., Carbon & Nutrient Fluxes in Continental Margins (2010)

Figure 1. Examples of important transport processes that are unique to or intensified along continental margines.

Carbon burial and sediment exchange in continental margins

Multiple processes, controls & feedbacks

Physical, chemical, biological interactions between benthos & seabed



Controls on carbon burial and sediment exchange

1) External forcings:

a) Carbon inputs

- autochthonous & allochthonous
  (spatial, seasonal, event-scale variability)

b) Sediment accumulation rates

- magnitude of SAR
  (steady-state vs. event-scale)

c) Exposure to efficient oxidants

(e.g., oxygen exposure time; Harnett et al., 1998)

- bottom water O_2
- biological/physical mixing
  (surface mixed layer depth)
- sedimentation rate
- transit to final burial

Factors control carbon burial and sediment exchange in continental margins:

2) Inherent Factors

a) Lability/recalcitrance of organic structures

- preferential preservation/degradation

b) Protective matrices

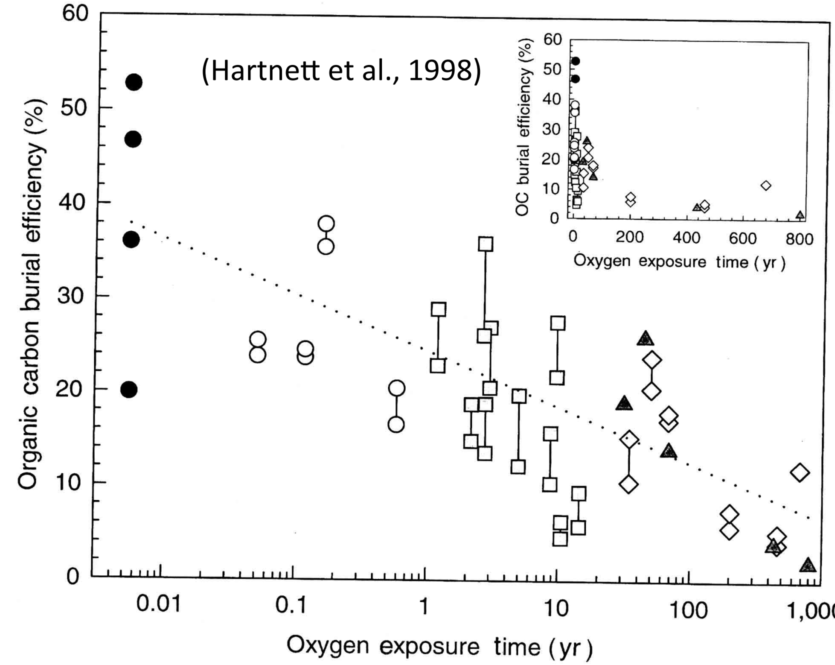
- inorganic matrices (e.g., mineral surface area)
- organic matrices (e.g., encapsulation)

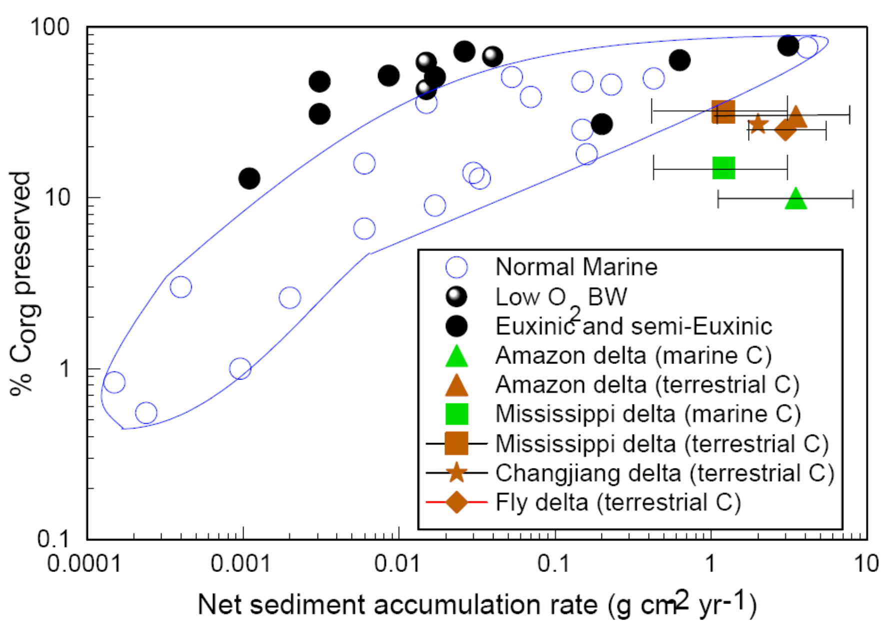
c) Diagenetic 'side-reactions'

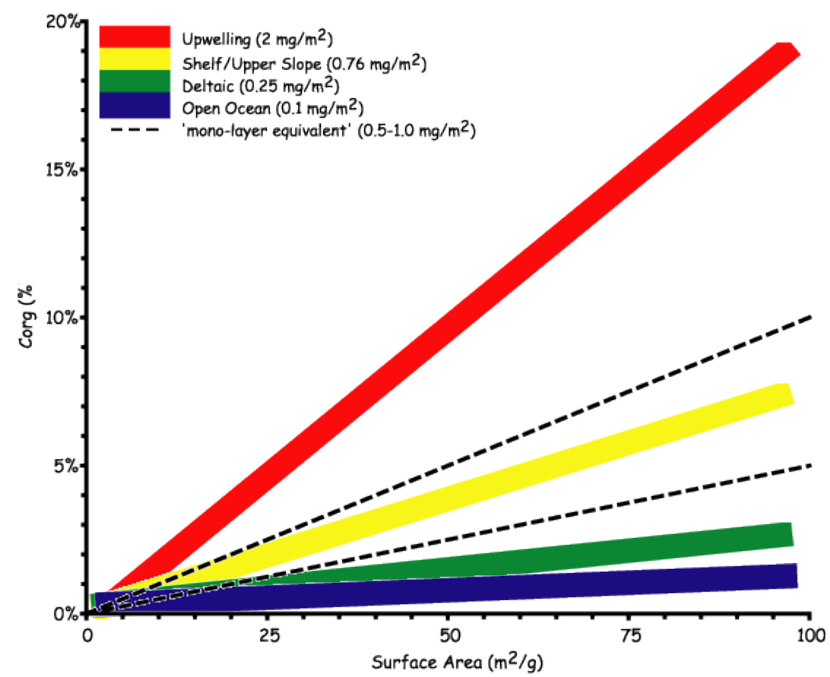
- Humication reactions (e.g., melanoidins)
- S-bound molecules (e.g., Tegelaar et al.,
- Fe-bound organic matter (e.g., Lalonde et al., 2012)

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!







Poor spatial coverage in:

Sediment mass accumulation rates (MARS)
Sediment/water exchange rates
Organic carbon concentrations

Inadequacy of "open ocean" approach to coastal ocean
- ➔ highly heterogeneous
- ➔ steep spatial gradients

Example of MARS estimates at low vs. high resolution:

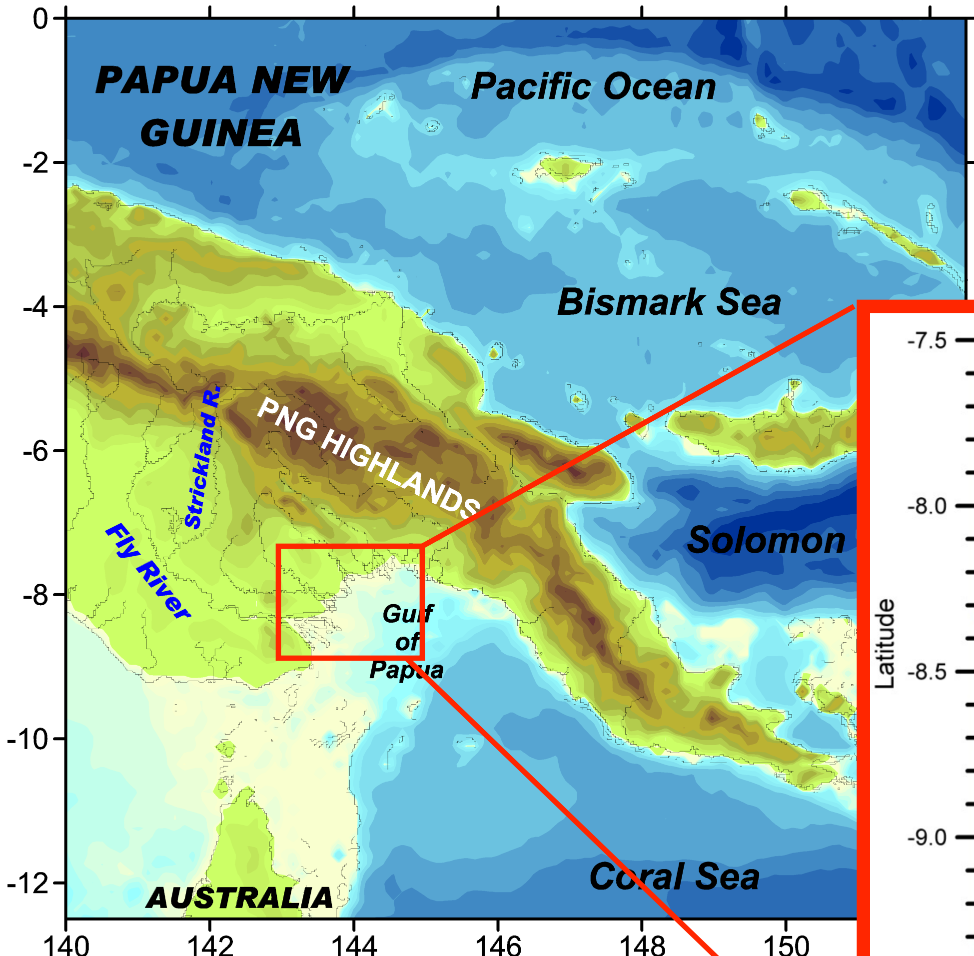
Gulf of Papua Shelf, ***West coast of US***

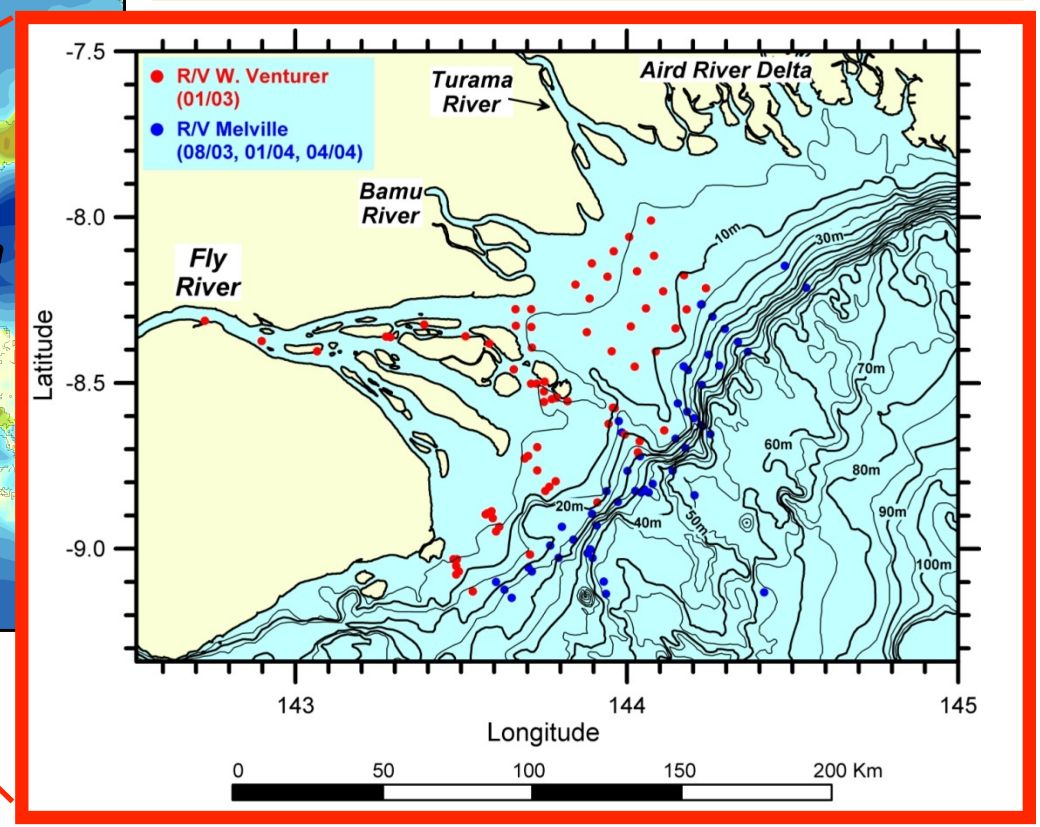
Inadequacy of "open ocean" approach to coastal ocean
- **➔ highly heterogeneous**
- **➔ steep spatial gradients**

Shelf environments in the Gulf of Papua studied under S2S

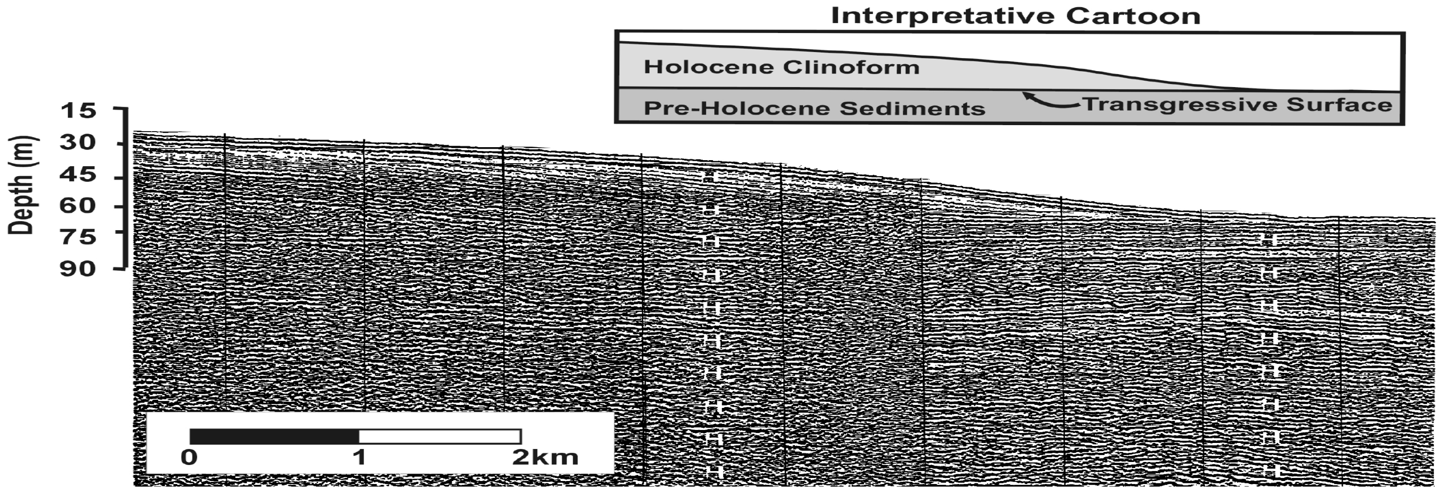
NW Gulf of Papua

- High River discharge
- Mesotidal
- Variable wave regime
- *Active clinoform*

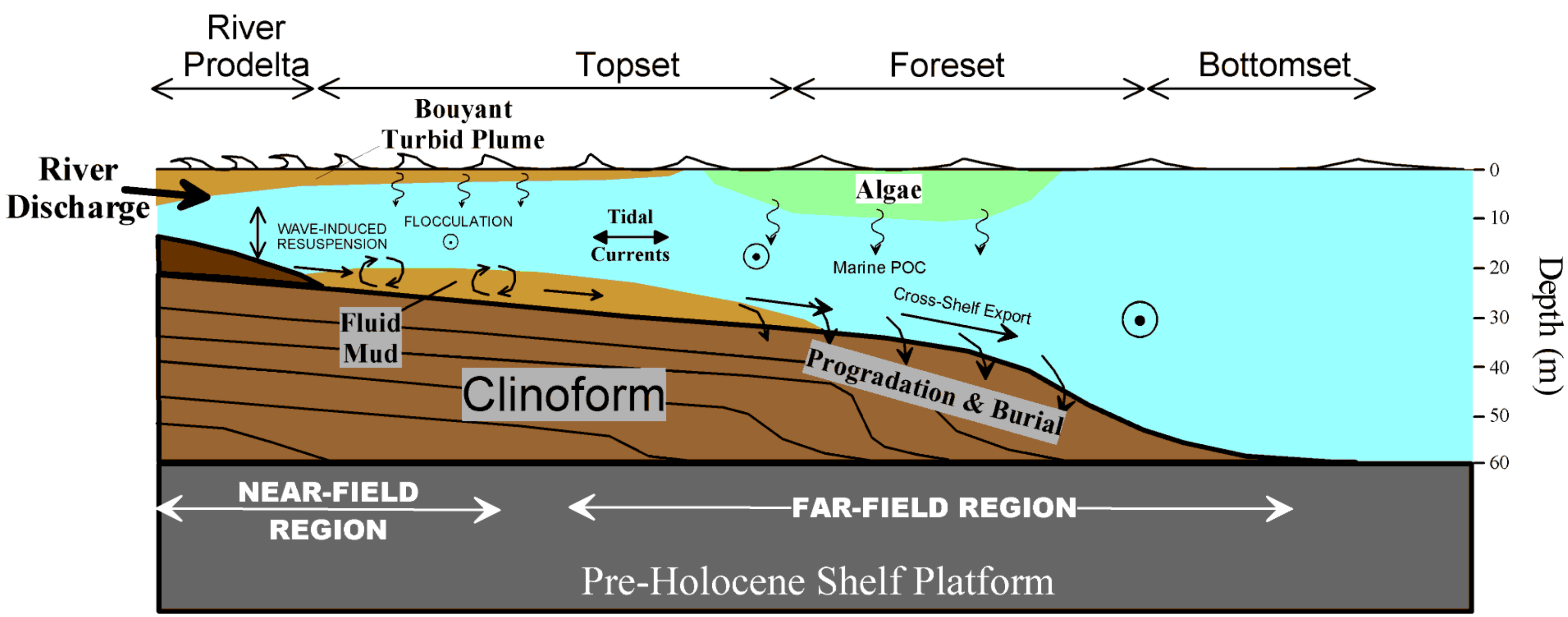




Shelf Clinoform: Key feature and focus



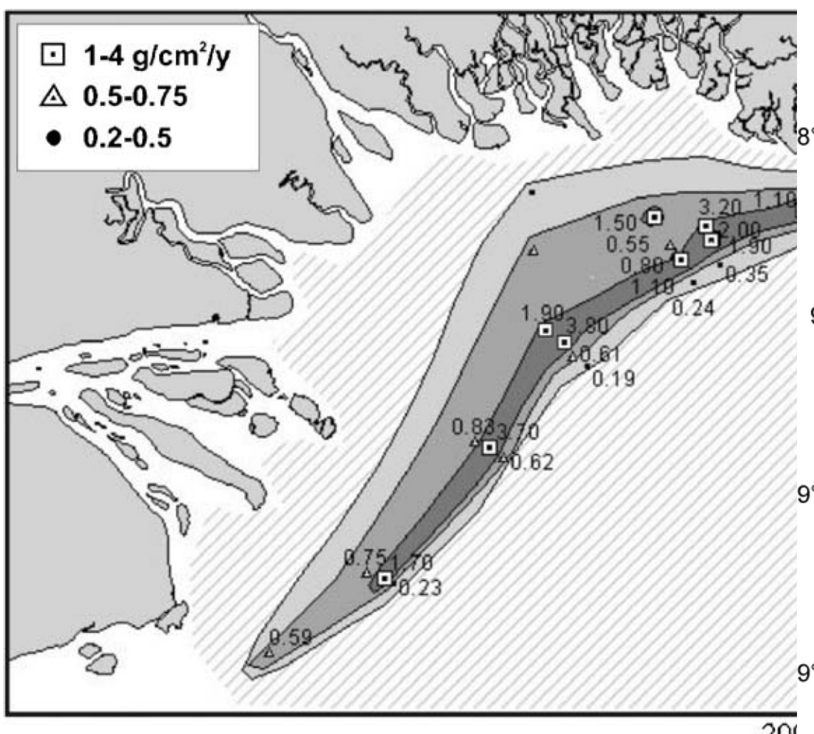
Particle Transport Processes

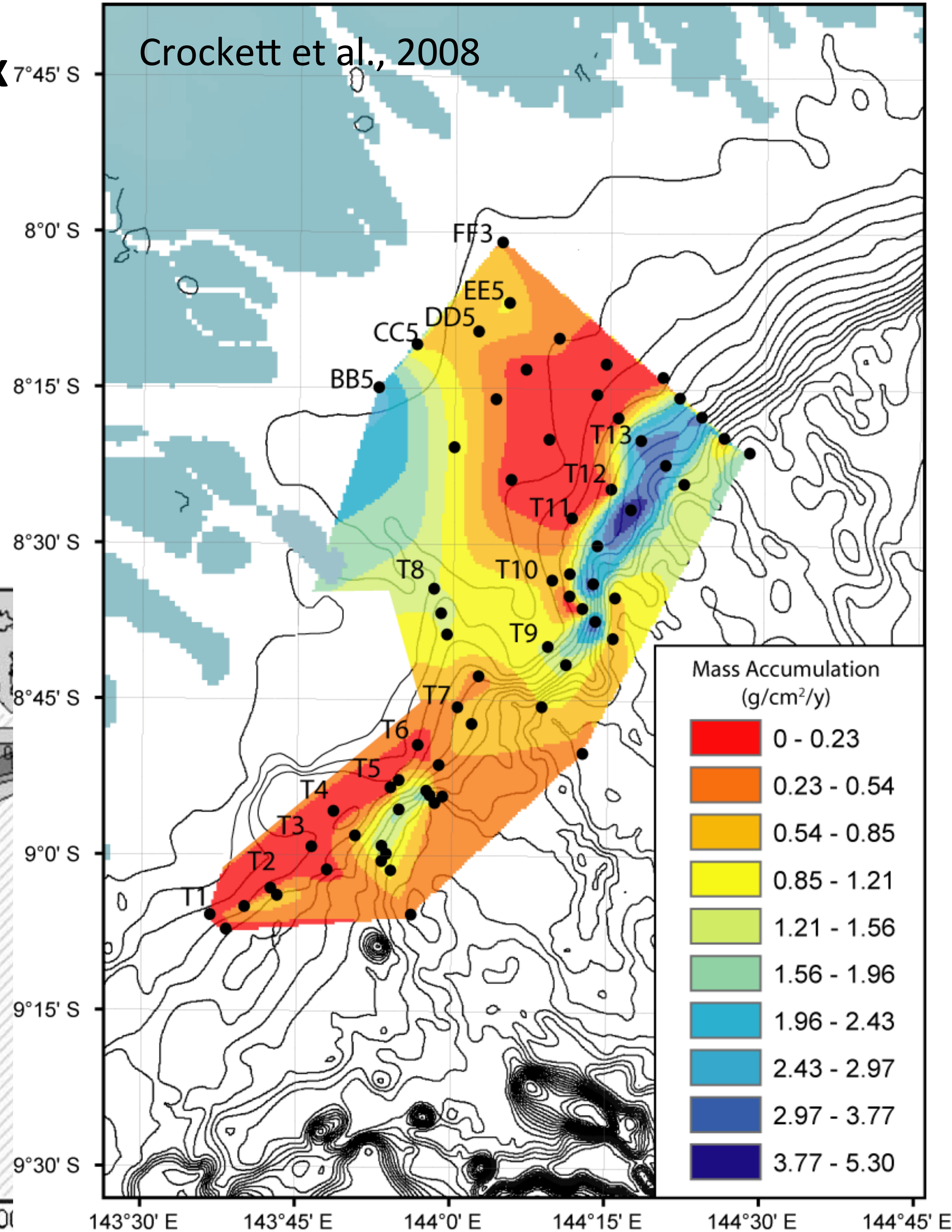


A more realistic and complex picture of long-term sedimentation

- Highest rates along foreset
- No accumulation outer foreset
- NE/SW contrast associated with sediment supply & routing

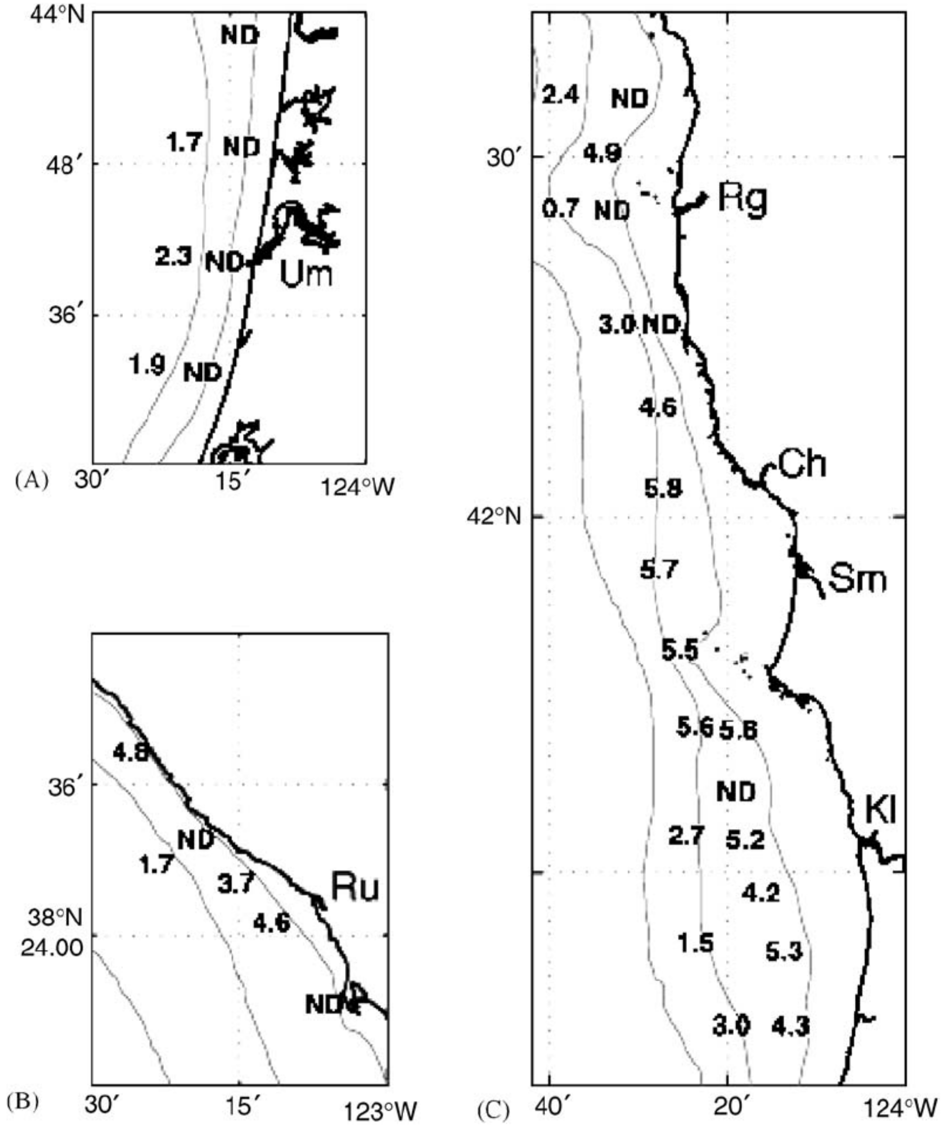
Walsh et al., 2004





River sediment flux and shelf sediment accumulation rates on
the Pacific Northwest margin

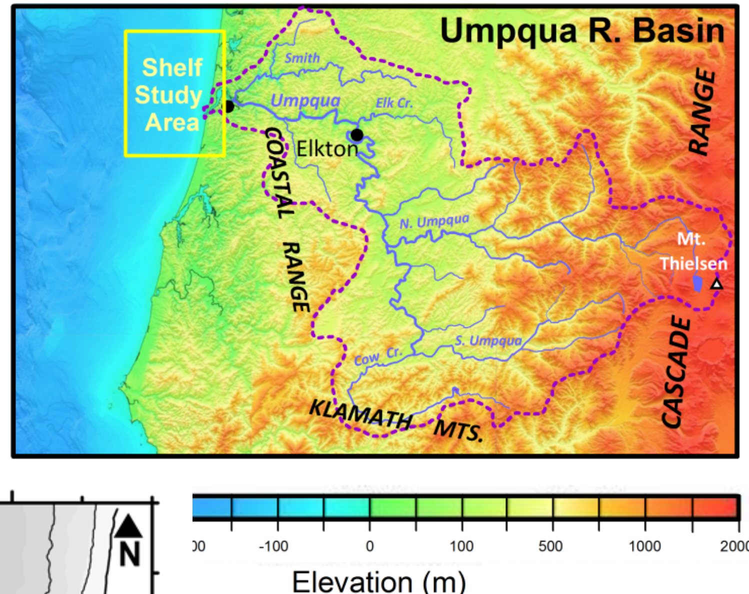
I

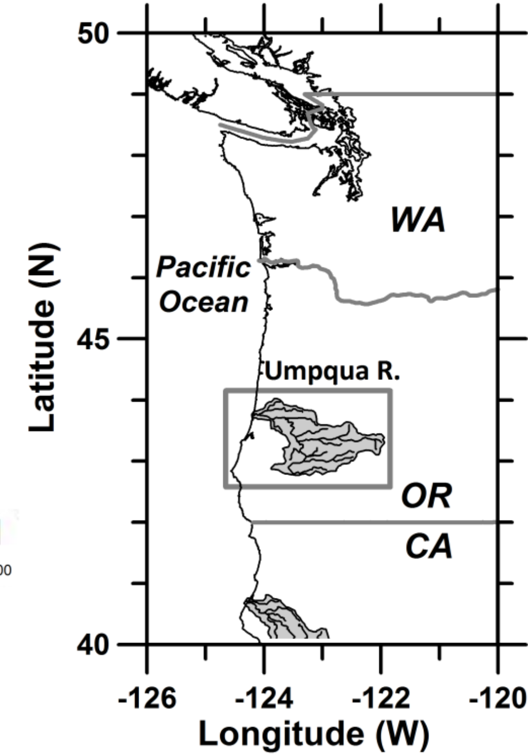


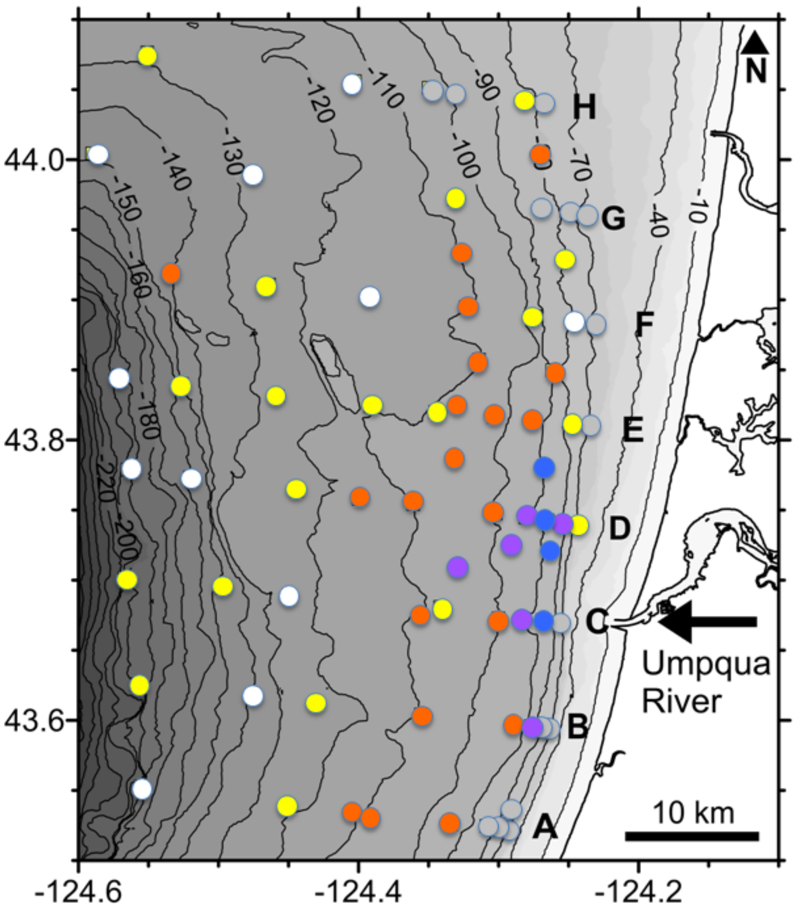
g. 10. Summary maps of SARs (in mm/yr) from ^{210}Pb geochronology for the (A) Umpqua (Um); (B) Rogue (Rg) and Klamath (Kl); d (C) Russian (Ru) river margins. Bathymetric contours are 50, 100 and 200 m. ND = not determined.

Fluvial Impacts on West Coast Margins

(*Hastings et al., 2012; Wheatcroft et al., 2013*)





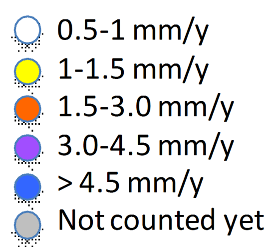


Recent Studies:

Characterization of ***shelf-depocenters*** associated with coastal rivers (such as Umpqua R)

Areas of higher accumulation rates found along inner to mid-shelf

➔ Result of sediment delivery during floods and wave climate.

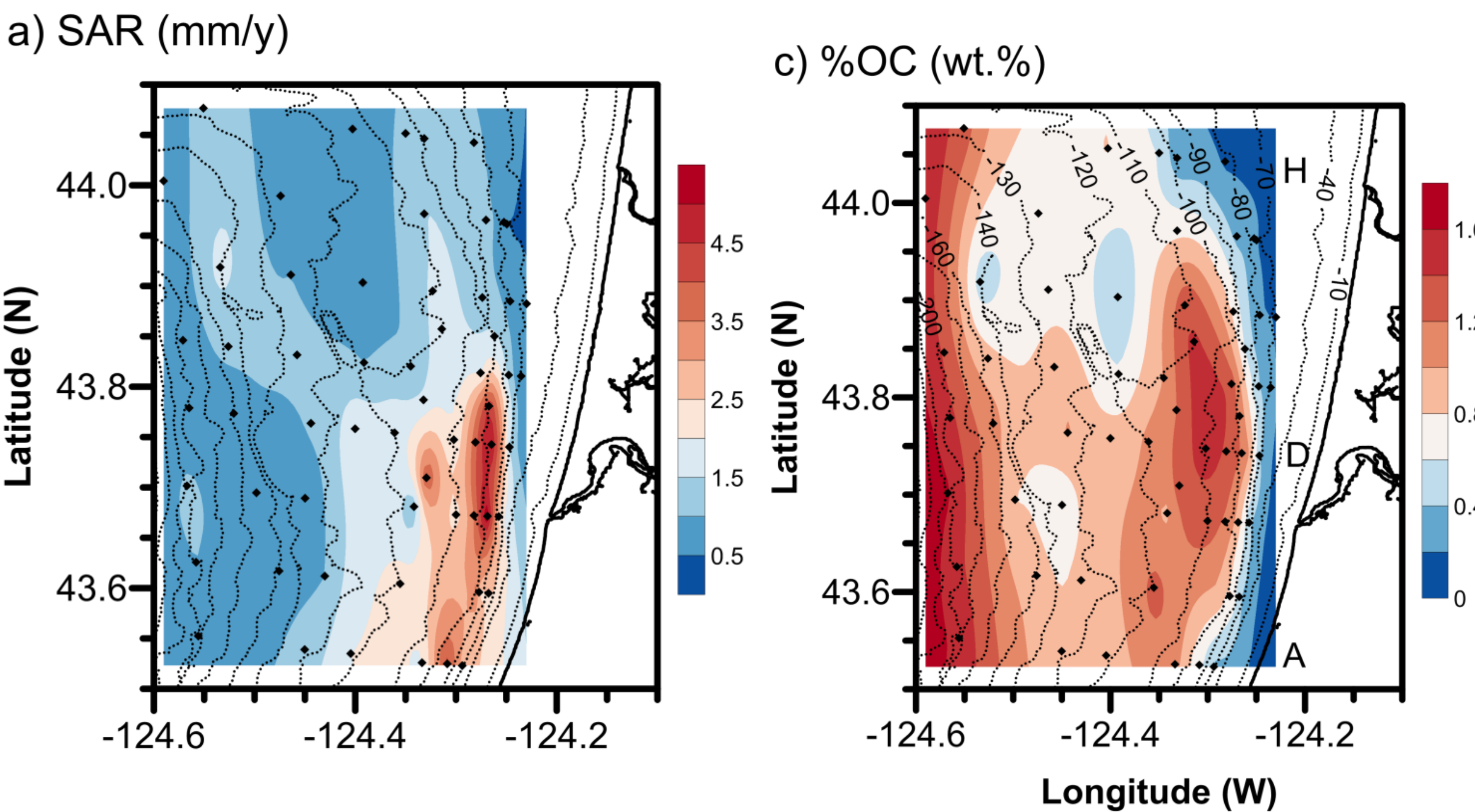


(Kniskern et al., 2011)

Spatially-Variable Accumulation Rates & OC Content/burial

- Role of fluvial depocenters
  ➔ Locally elevated accumulation rates

- Sediments enriched in organic carbon and land-derived materials



Issue of variability in time-scales of measurements:

Sediment/water exchange rates:

- Eddy covariance (hours)
- Benthic landers (hours/days)
- Pore-water profiles (days/weeks)

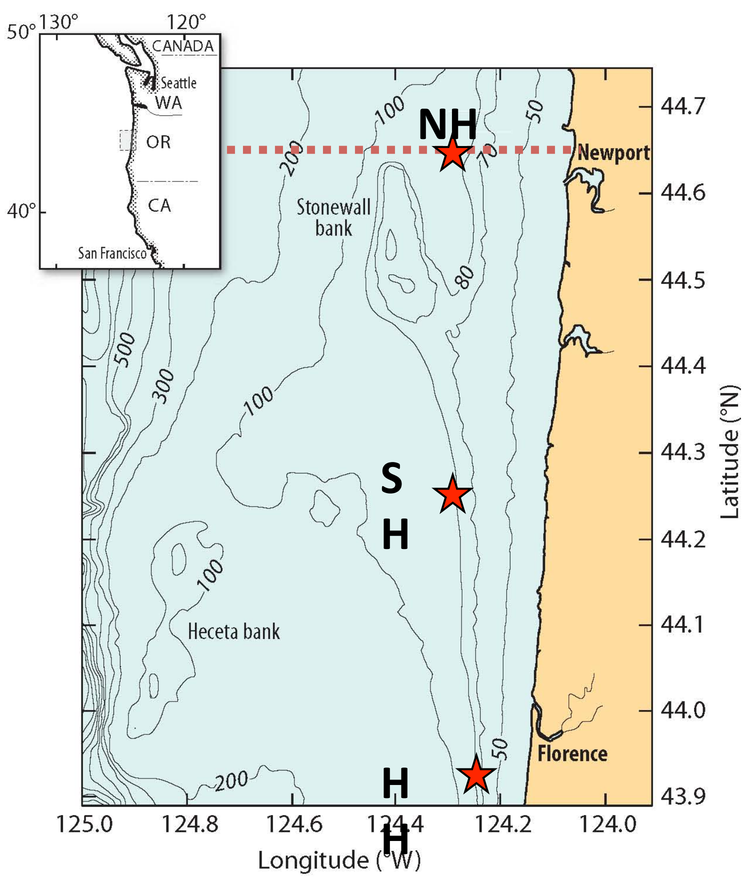
➔ Need for seasonal adjusted rates to get to annual fluxes

Issue of timescales

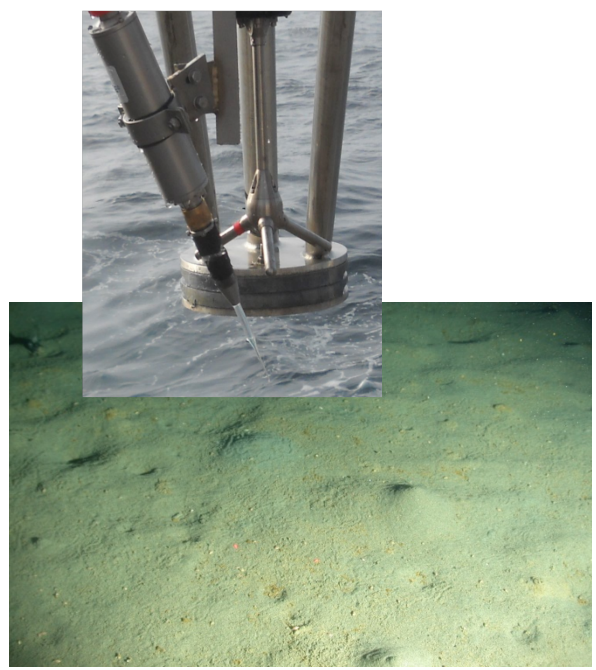
Forcings affecting benthic carbon processes in coastal ocean range from hours to decades

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

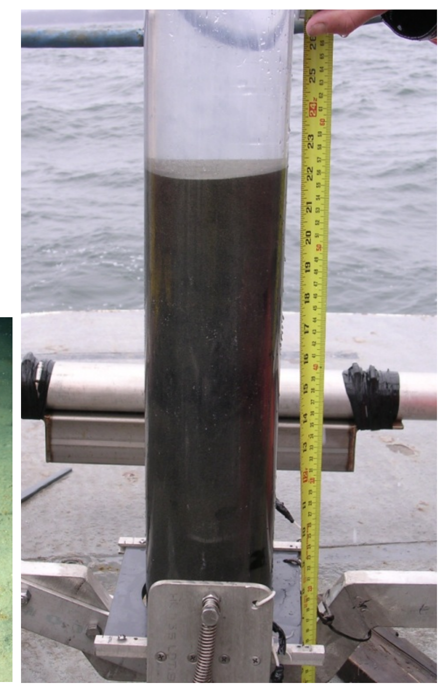
Example: Benthic O2 Consumption (Clare Reimers)



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



Traditional Porewater Diffusion Method



Mass accumulation rates:

7Be – based estimates (days/months)

210Pb, 137Cs-based estimates (decades)

14C-based estimates (centuries)

Need to consider issue of time-dependency on rates

(non-steady inputs, hiatuses)

'classic' geology paradigm

On sediment accumulation rates and stratigraphic completeness: Lessons from Holocene ocean margins

Christopher K. Sommerfield

Continental Shelf Research 26 (2006) 2225–2240

Short term rates are systematically faster than longer term rates.

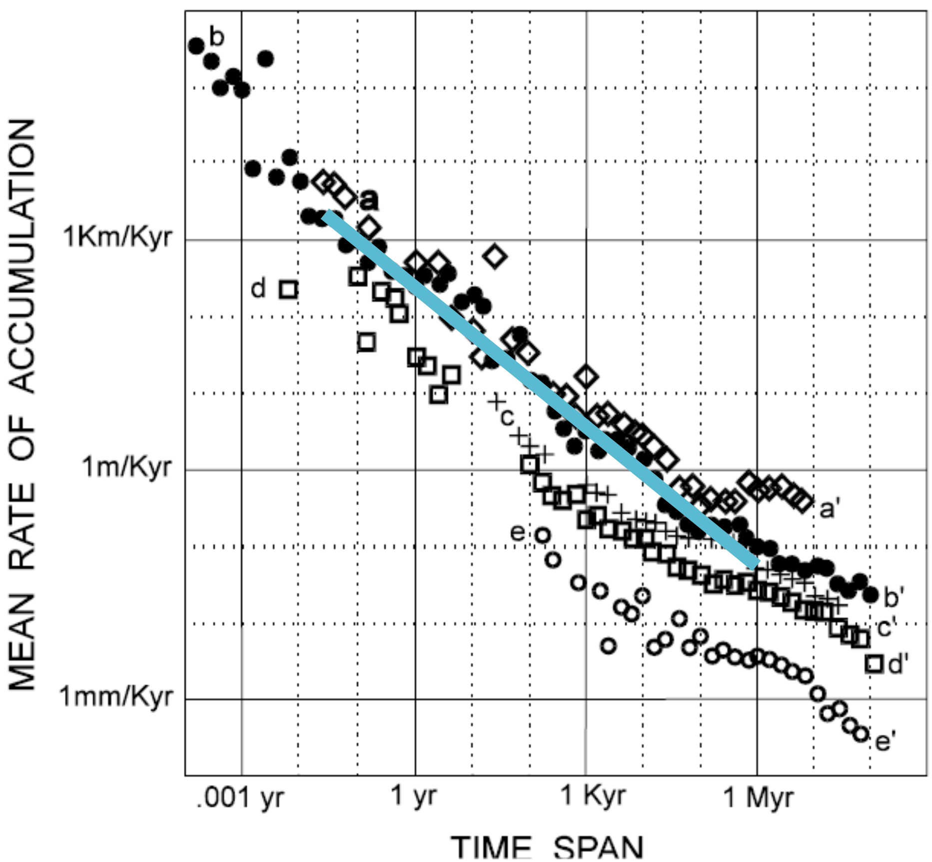


Figure 4. Mean accumulation rates for terrigenous sediments on passive continental margins. a-a': deltas (diamonds; 2,988 empirical rate determinations); b-b': shelf seas (filled circles; 22,636); c-c': continental slopes (crosses; 6,421); d-d': continental rises and abyssal plains (squares: 10,821); e-e': abyssal red clays (open circles; 2,215).

Accumulation Rates in Deltas

Time span of measurements:

Isotope	Half-life
Be-7	53.3 d (0.15 y)
Pb-210	22.2 y
C-14	5,730 y

Expected Delta Accumulation Rates:

Isotope Used	Sed. Rate
Be-7	~10 cm/y
Pb-210	~1 cm/y
C-14	~0.1 cm/y

Key Questions for this group (Areas of Fertile Research?)

How do we reconcile these various estimates collected at such different time-scales?

What is the appropriate context/approach to compare estimates of carbon burial *[integrated in sediments over several decades]* with a annual estimates of CO_2 exchange *[estimated from single/multiple cruises in a given year]*?

Issue of time-varying, non-steady state inputs (e.g. MARs off Oregon) ➔ *Wheatcroft et al., Marine Geology, 2013*

Final thoughts and suggestions:

Increase coverage of benthic processes

➔ Need for more observations

- spatial/seasonal surveys of MARs, OC are NEEDED
- remote techniques (e.g., mapping of backscatter properties) should be encouraged
- Inclusion of benthic processes in OOI activities to evaluate temporal variability in burial/sediment exchange fluxes

➔ Need for processed-based studies to

- reconcile observations at different time- and spatial-scales
- evaluate key controls on burial efficiency
- develop realistic models that include key processes

➔ Promote efficient mechanisms to fund pelagic/benthic coupling studies

- enable cross-disciplinary studies
- include studies of processes (e.g. land-ocean lateral fluxes) relevant to the carbon sink at regional/global scales