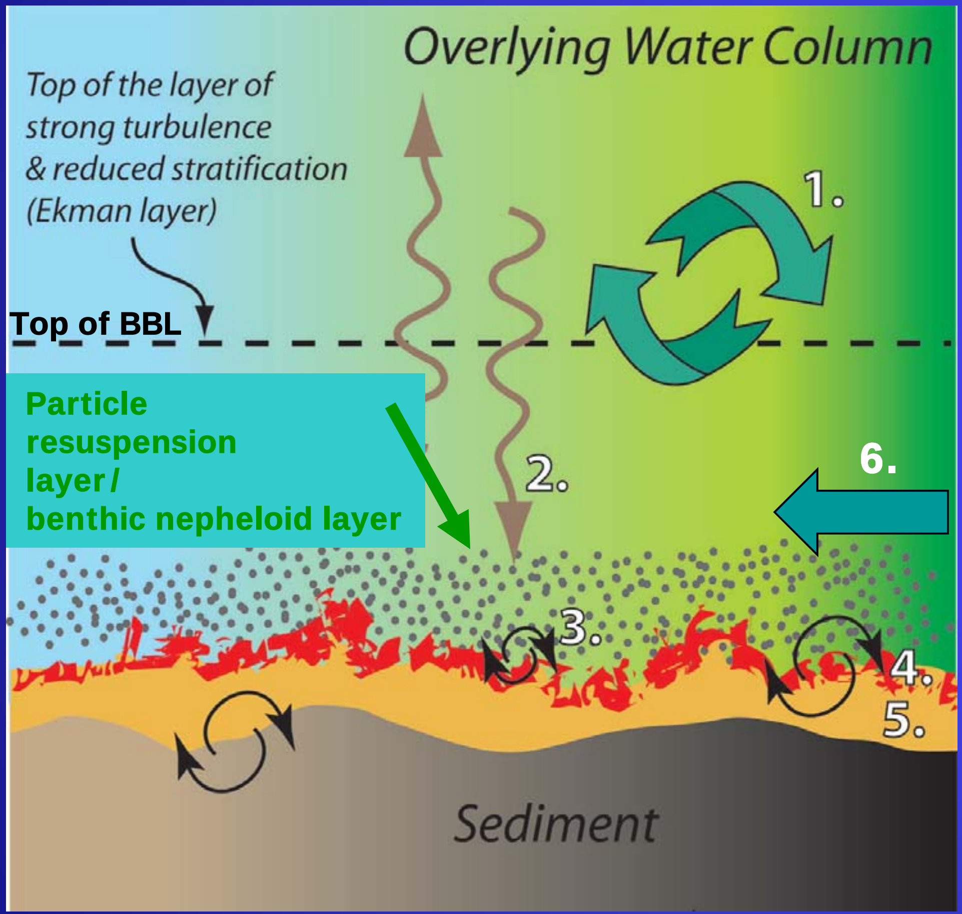
Benthic nepheloid layer dynamics and potential role in carbon cycling on continental margins

Cindy Pilskaln
University of Massachusetts
School for Marine Science and Technology
New Bedford, MA

Ocean Carbon and Biogeochemistry Workshop
July 2010

Scripps Inst. of Oceanography

Schematic diagram of major fluxes within the Benthic Boundary Layer: Interface between pelagic and benthic environments



1. Exchange of BBL-interior water by turbulent eddies and advection.

2. Particle sinking and resuspension; migrating zooplankton.

**Common occurrence of physically maintained, intermittent or permanent particle resuspension layer = Benthic Nepheloid Layer (BNL)

3. Exchange of dissolved, colloidal, and suspended particle matter across the sediment-water interface.

4 & 5. Bioturbated sediment mixing zone : injection and modification of particulate, colloidal and dissolved material.

6. Lateral advection input of material.

Modified from CBED Rept., 2004

Benthic Nepheloid Layers in the Ocean:

For many years interest and focus on deep BNLs @>2 km (e.g., McCave, Biscaye, Eittrem, Spinrad, Gorsline, Ewing).

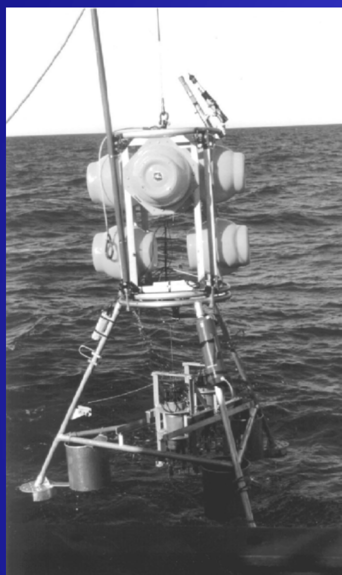
Layer was primarily defined and recognized by substantial increase in suspended particles indicated by significant increase in light attenuation and extending to sediment-water interface.

Found along base of deep slopes and in abyssal basins strongly influenced by western boundary currents and deep penetrating eddies→ thus driven by deep energetic flows.

Composition assumed and found to be largely lithogenic—fine clays particles (2-5 μm) responsible for optical signature of high turbidity.

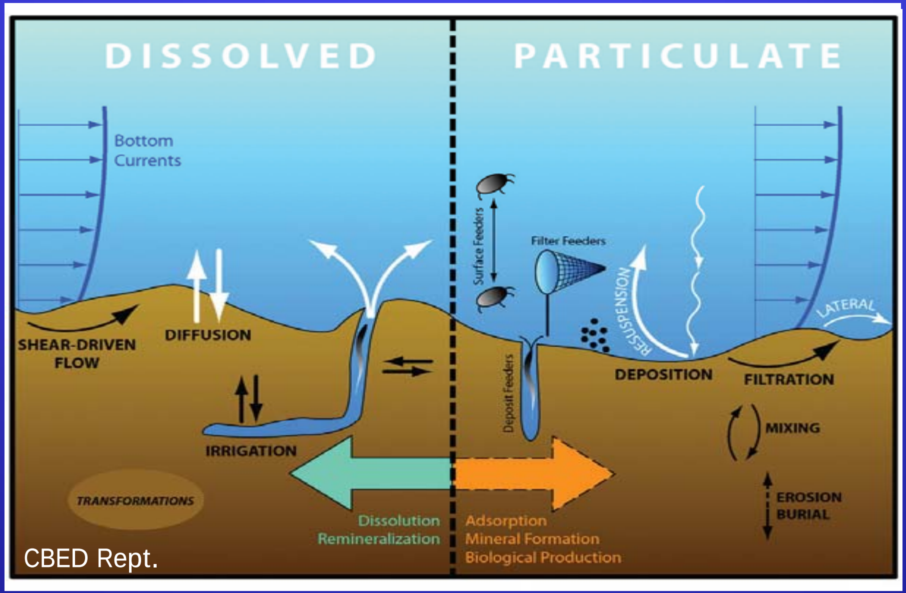
Close correlation between suspended particle mass (SPM) and attenuation indicates suspended matter in deep BNLs is refractory, high scattering mineral particles.

Increased examination of continental margin BNLs, biological rate studies and new optical and particle collection technologies reveal a far more geochemically, biologically, and physically dynamic BNL with a variable and diverse particle population .



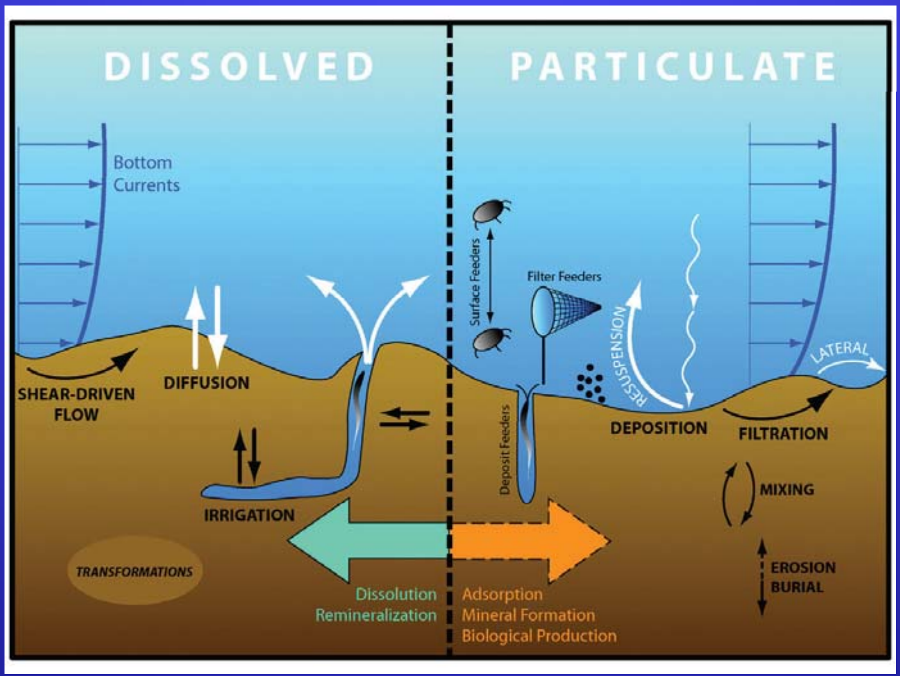
Optical and pump studies: BNL contains mm-size flocs, light scattering AND absorbing particles→ lack of strong correspondence between c_p and SPM; strong quantitative relationship between c_p and POC; variable PSD with depth in BNL impacts cp; aggregation and disaggregation of organic detrital particles (Boss, Biscaye, Bishop, Hill, Pilskaln).

Geochemical and optical studies: organic matter in BNL→ labile POM such as chlorophyll; tightly bound aged organic carbon on clays; seasonal variation in delivery of POC and biogenic minerals to BNL; pulsed inputs to BNL of N-compounds from sediments; variable CDOM concentrations.; elevated protein, POC, PON vs. immediately overlying clear water (Ransom, Pilskaln, Townsend, Christensen, Mayer).



Biological and chemical studies: HIGH zooplankton biomass, diversity and grazing/respiration rates in BNL; attached and free-living bacterial communities distinguishable from surface water communities; elevated protozoan biomass relative to overlying particle-free water (Smith, Wainright, Wishner, Puig, Townsend, Rooney-Varga)

Physical flow/optical/chemical studies: significant role of tidally generated internal waves in forming and maintaining margin BNLs; seasonal storms and inflow of slope waters onto shelf→ increased turbidity and nutrient injection to BNL (Fanning, Drake, Cacchione, Grant).

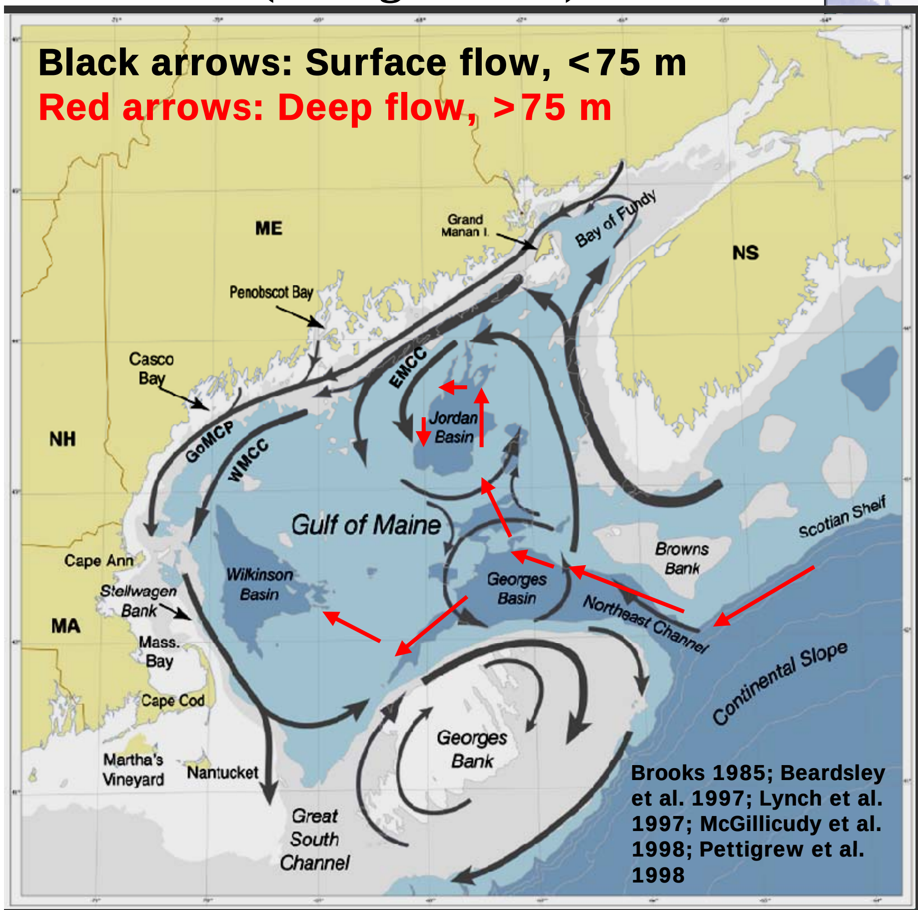


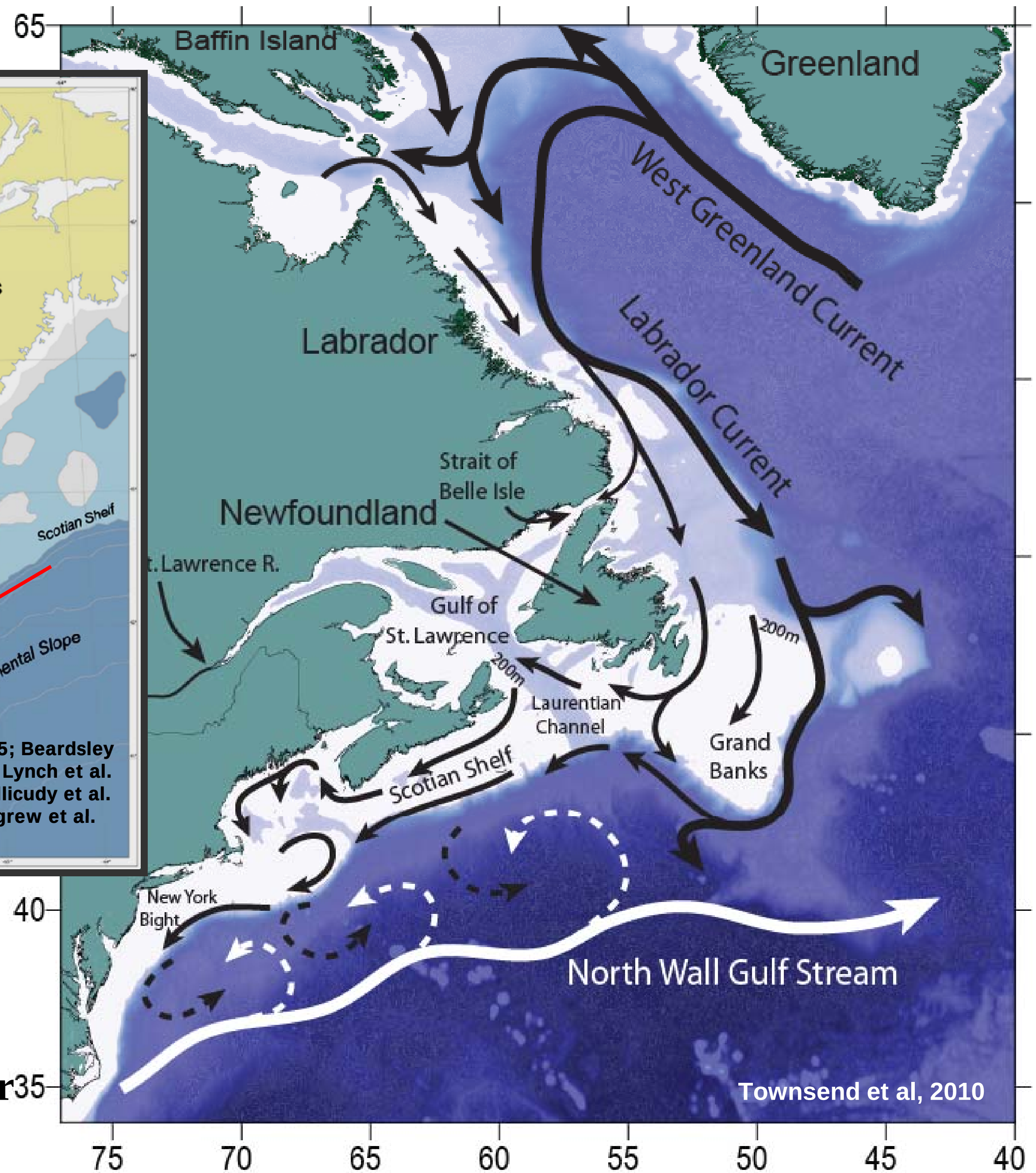
Diverse data sets indicate that BNL is a distinct environment within which biologically and physically-driven, particle-based chemical transformations occur and represent early diagenetic reactions, thus impacting the balance between remineralization and the benthic delivery of PON and POC over variable time scales.

Common occurrence of BNLs on the continental margins where POC production, export, benthic remineralization, and accumulation are maximal argues for better understanding of biogeochemical processes occurring in environment through which all particle matter must pass prior to sediment/water interface delivery.

Is the mismatch often observed between predicted POC delivery rates and carbon required to fuel benthic oxygen consumption due in any measure to POC modification in the BNL?

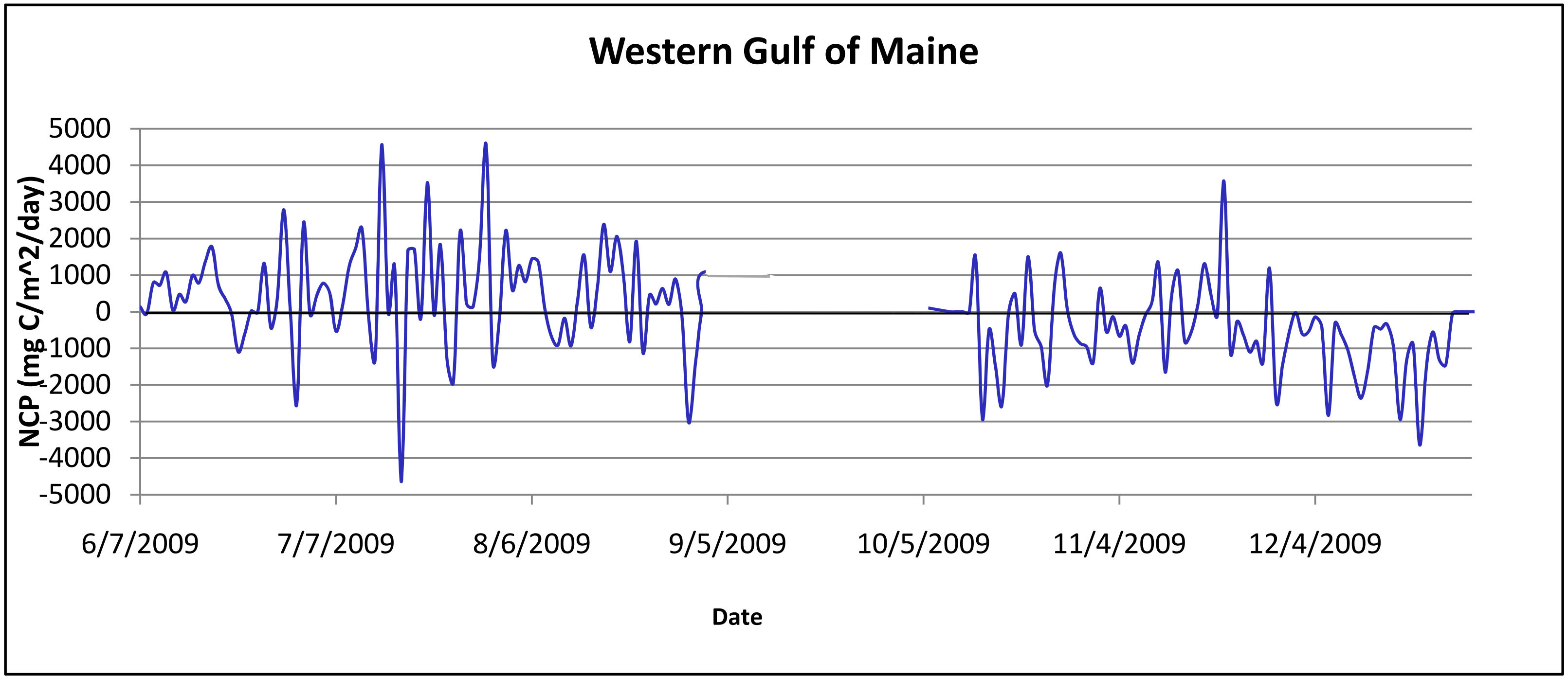
Gulf of Maine: Semi-enclosed shelf sea with several deep (~-300 m) basins, shallow ledges and extensive glacially-deposited sand bank (Georges Bank).





Strong tidal mixing, localized upwelling and periodic inflow of warm, nutrient-rich Warm Slope Water or cold, low salinity Labrador Slope Water.

Temporal variability in net community production (NCP = autotrophy – respiration integrated to 1% light level) from high-rate O_2 data (UNH Buoy)



Mass Balance Model:

$$NCP = Z \cdot \frac{d\Delta\left[O_2\right]}{dt} + F_s$$

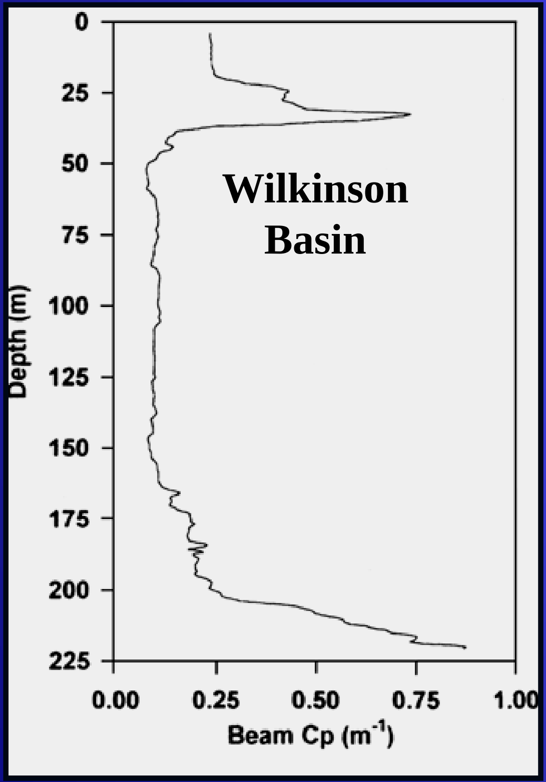
Mean Winter NCP = - 601 mg C/m^2/d

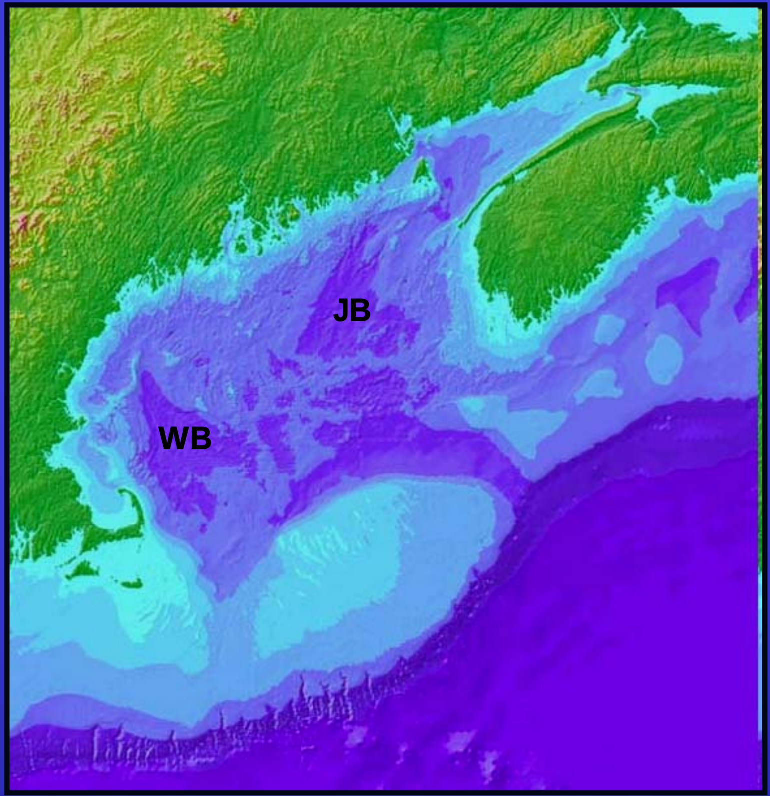
Mean Summer NCP = 485 mg C/m^2/d

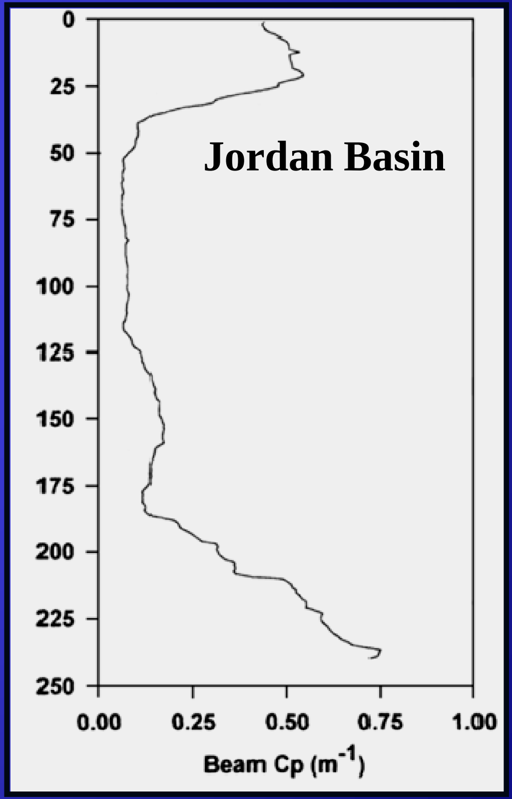
Salisbury and Vandemark, unpublished

Thick BNLs in basins: First documented with CTD/beam attenuation profiles in 1986 (Spinrad).

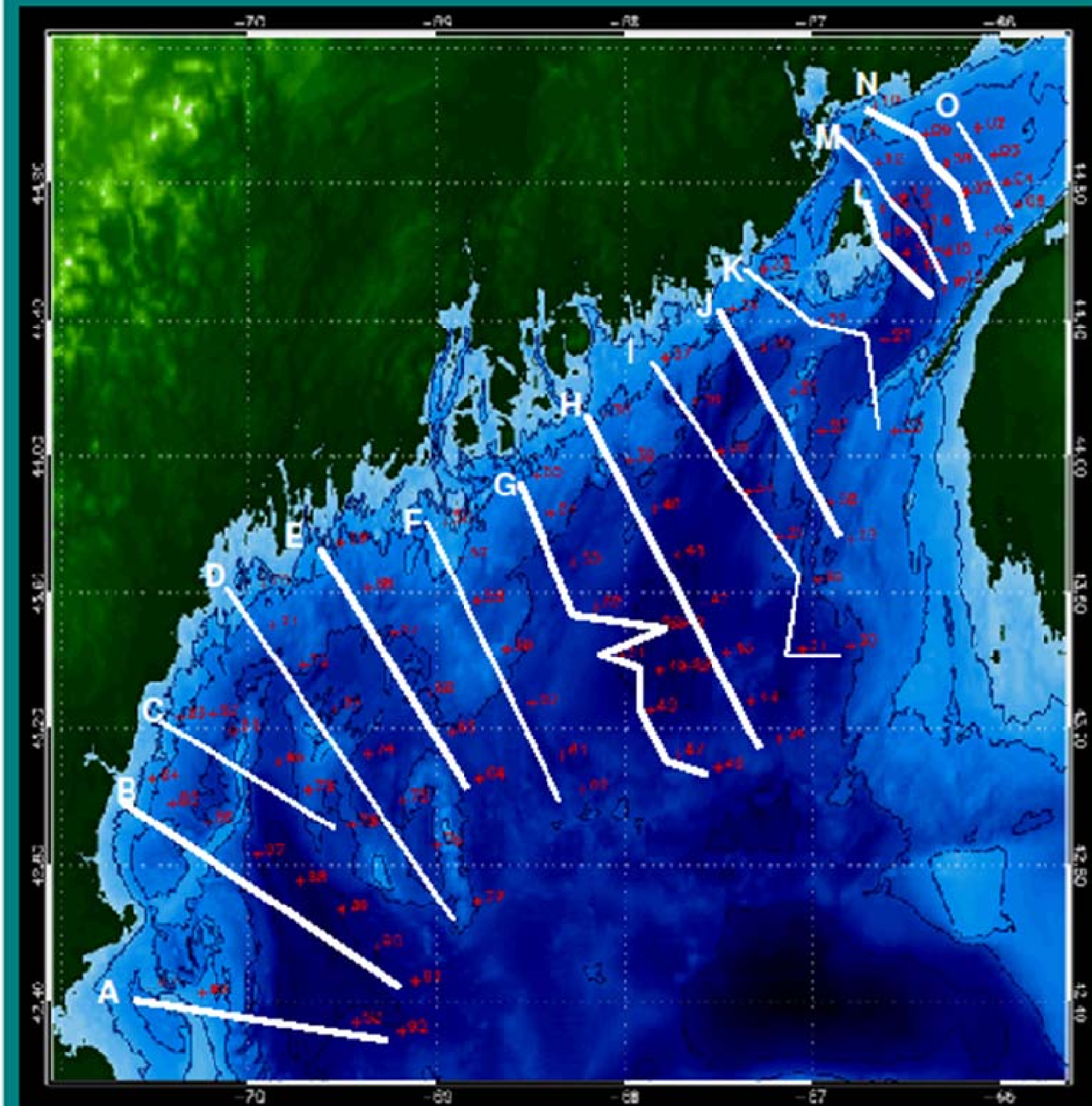
Found to be persistent and consistent feature of 10-30 m thickness throughout Gulf (numerous investigators, 1986-present).







Pilskaln et al., 1998; 2007, 2008



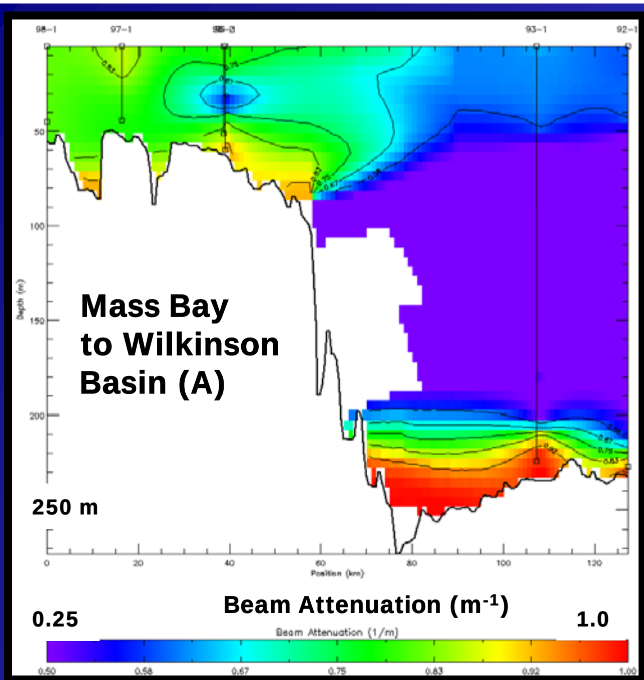
October 2004 BNL survey:

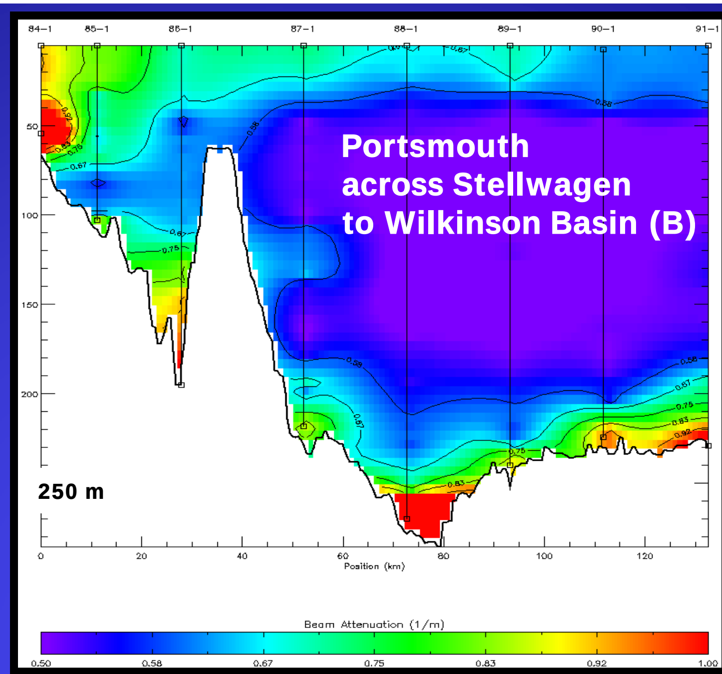
15 CTD & transmissometer transects from Mass Bay to Bay of Fundy

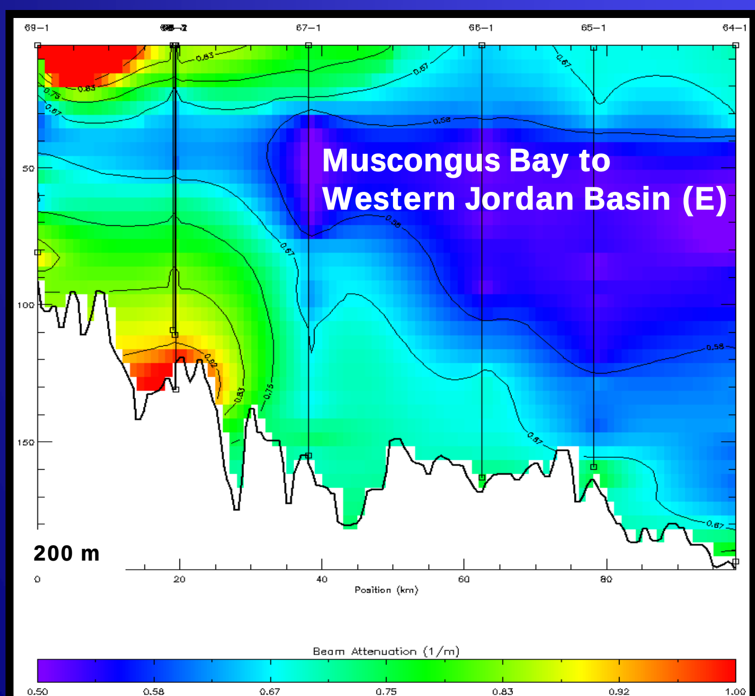
Transect lengths: ~50-150 km

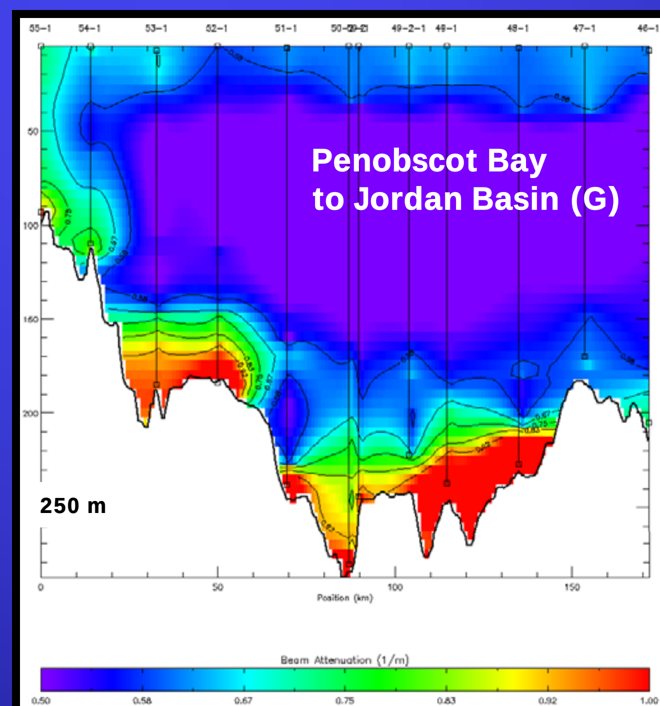
Bottom depth range: 50-300 m

Pilskaln et al. 2007; 2008







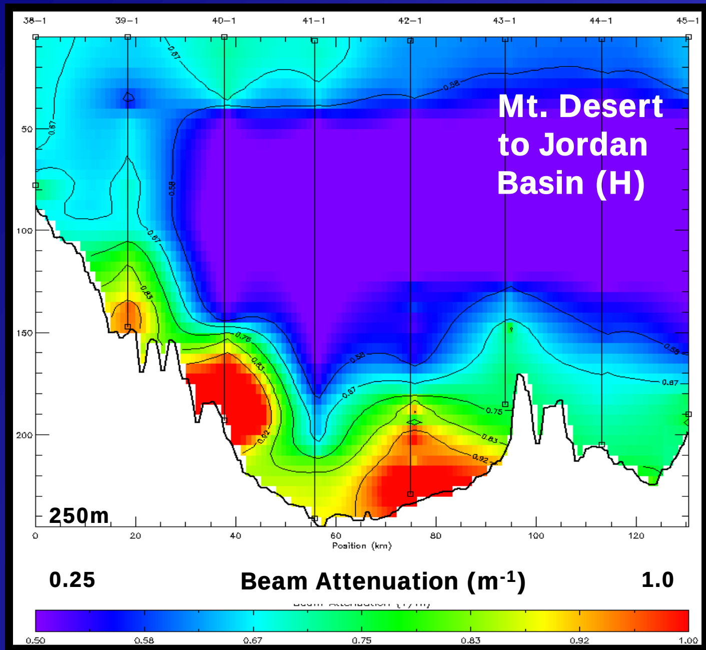


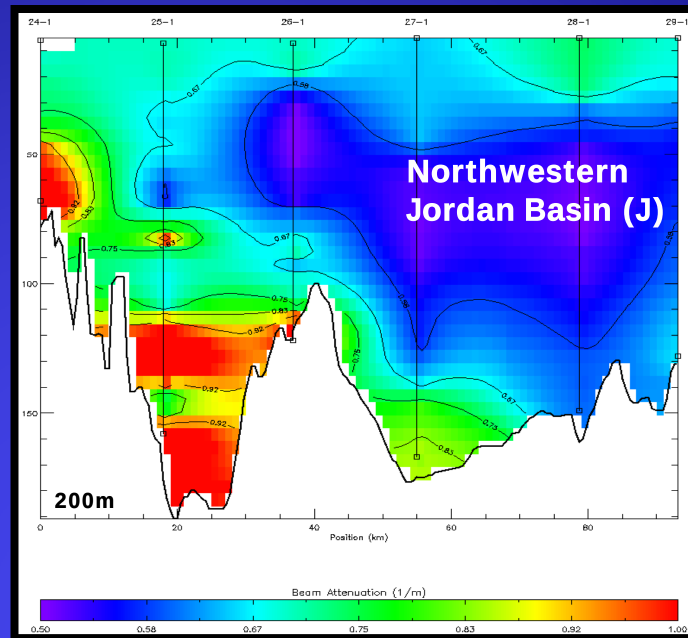
Examples of 2004 Gulf of Maine beam attenuation profile transects.

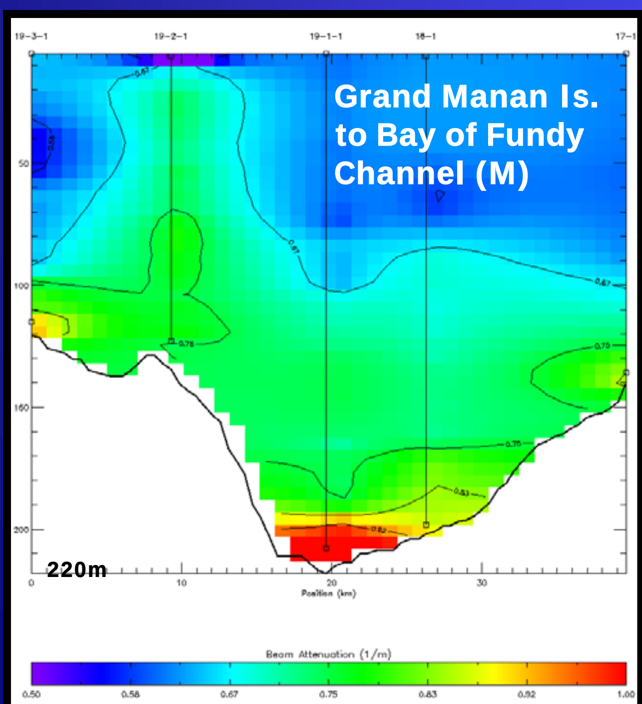
SPM (mg/l on GFF):
$\leq$0.5 blue-purple
>4.0 orange-red

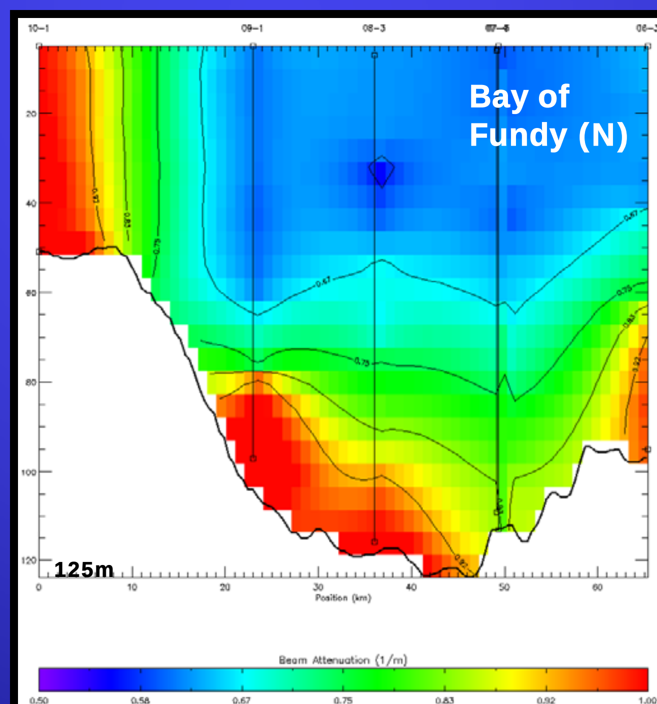
***Evidence of contour-aligned BNLs**

Deep coastal current and Gulf of Maine cyclonic circulation producing contour-focusing of BNL (?)









***Beam attenuation due to particles (c_p) vs. SPM relationship problematic in GoM:**

***Low r^2 value of 0.46**

Reflects particle diversity

=

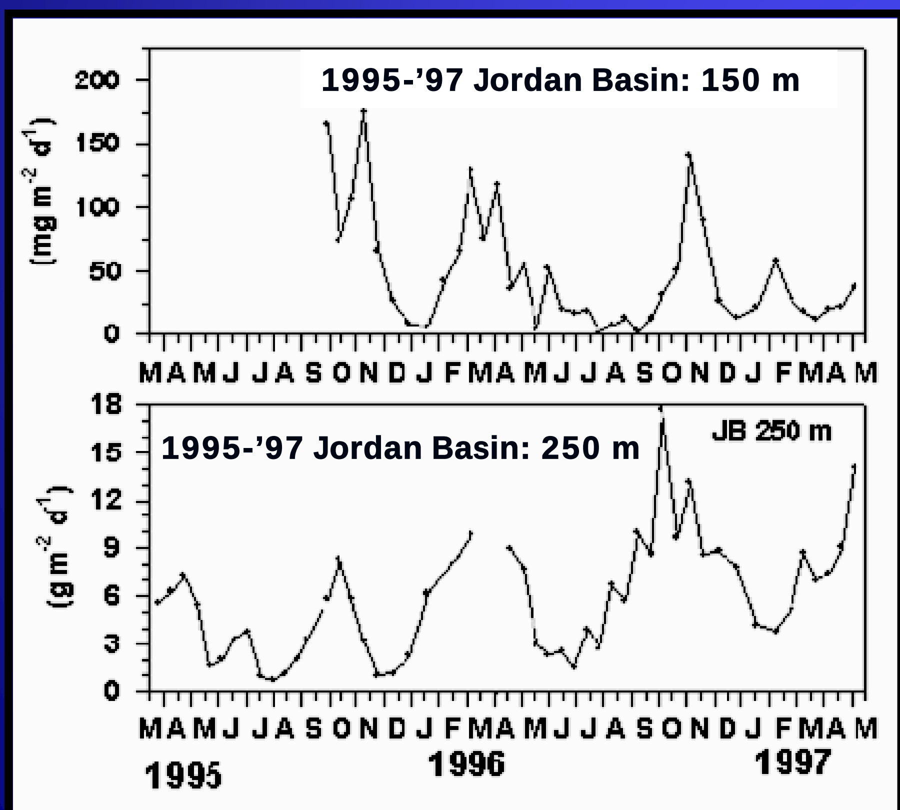
A mix of light absorbing & scattering, inorganic and organic particles

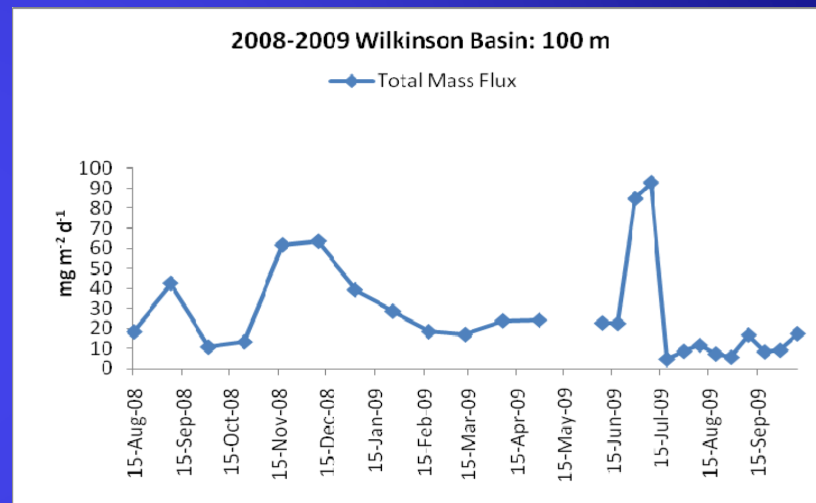
Not just suspended refractory clay minerals!

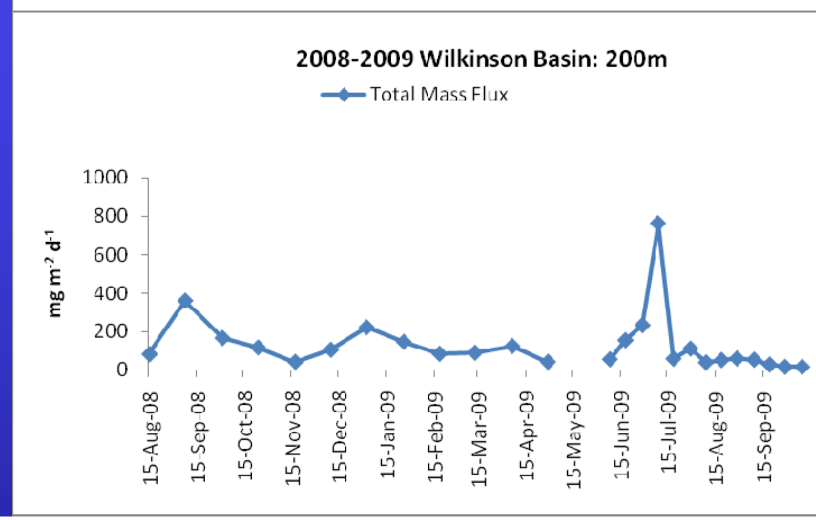
Time-series sediment traps: Substantially higher deep-water resuspension fluxes →
Clear evidence of active benthic nepheloid layers.

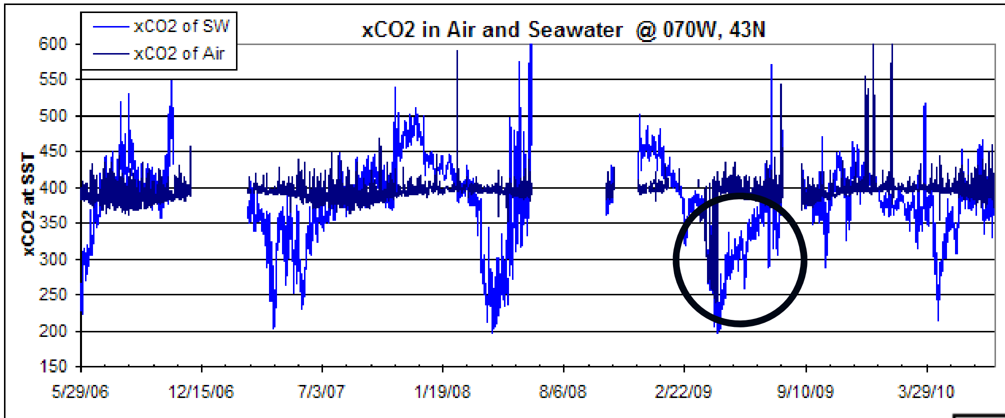
****Significantly higher resuspension fluxes in east (Jordan Basin).**

***Seasonal peaks in mass export commonly reflected in deep BNL resuspension fluxes.**





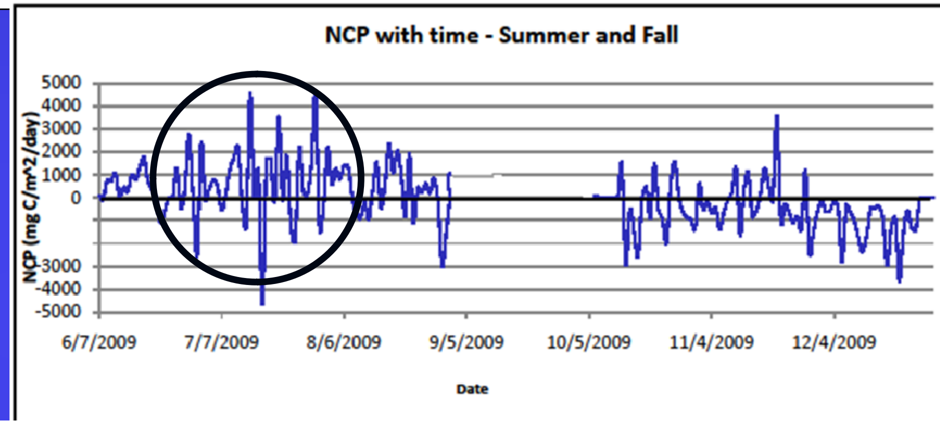


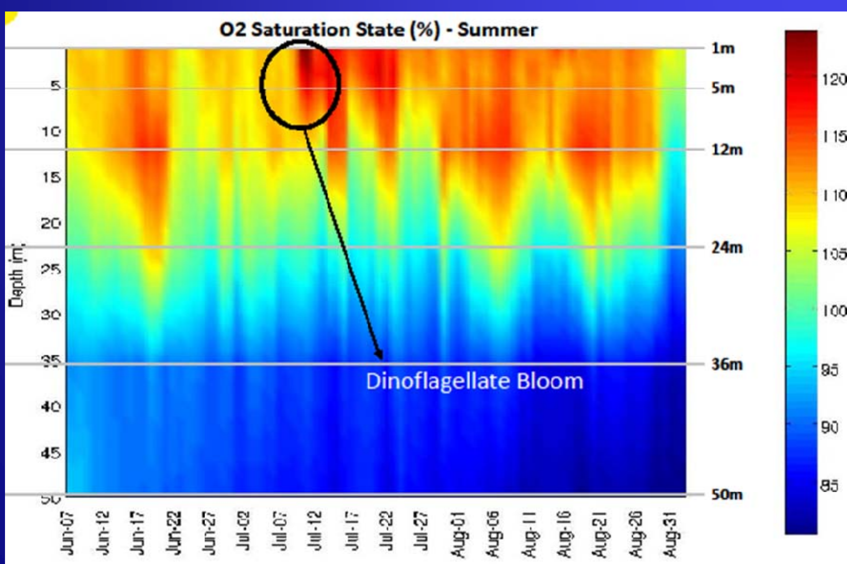


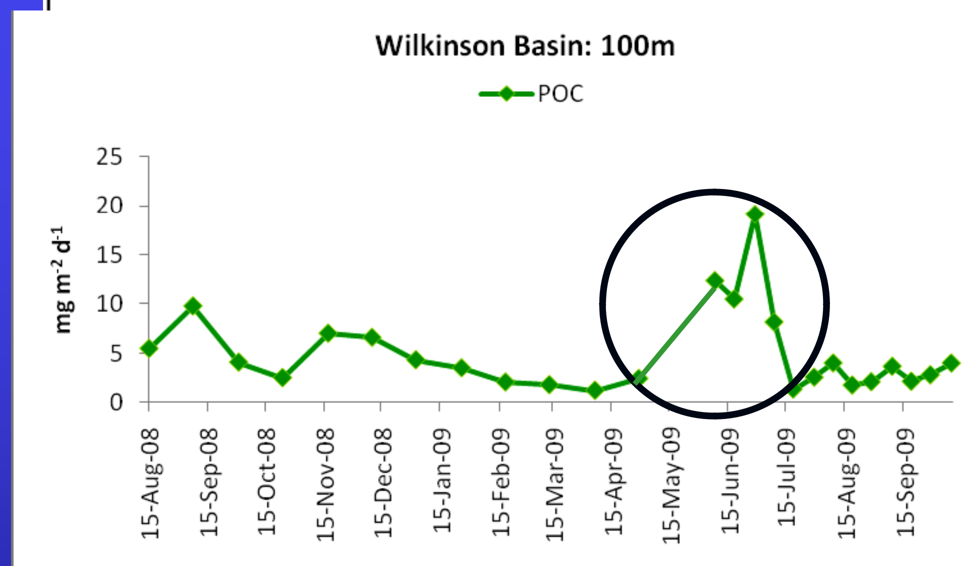
Translation of seasonal CO_2 uptake and 1^0 production to 100 m in Western Gulf of Maine/Wilkinson Basin:

High rates of remineralization leads to <u><</u>1% POC produced delivered to 100 m.

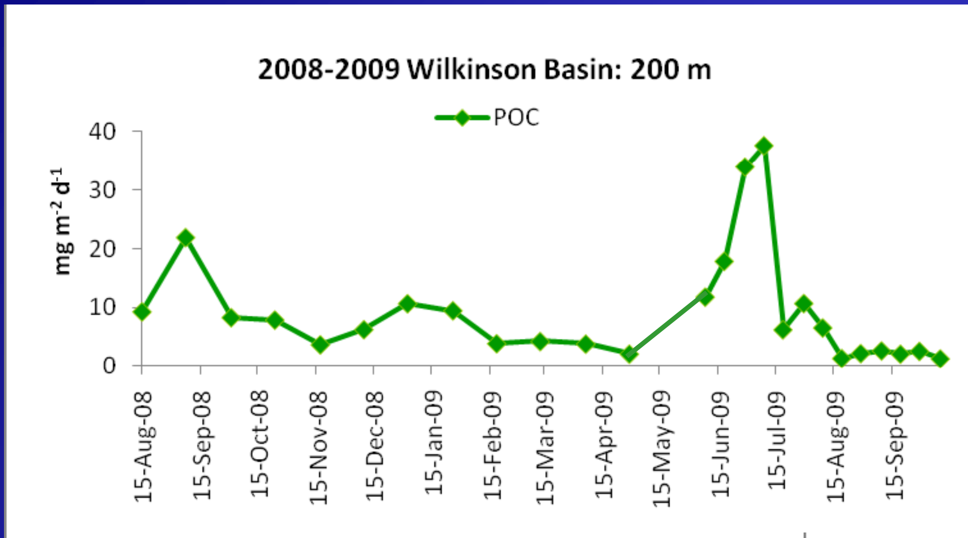
2009: Summer phytoplankton bloom--becoming more common in past few years--included a very large bloom of dinoflagellate *Alexandrium sp.*



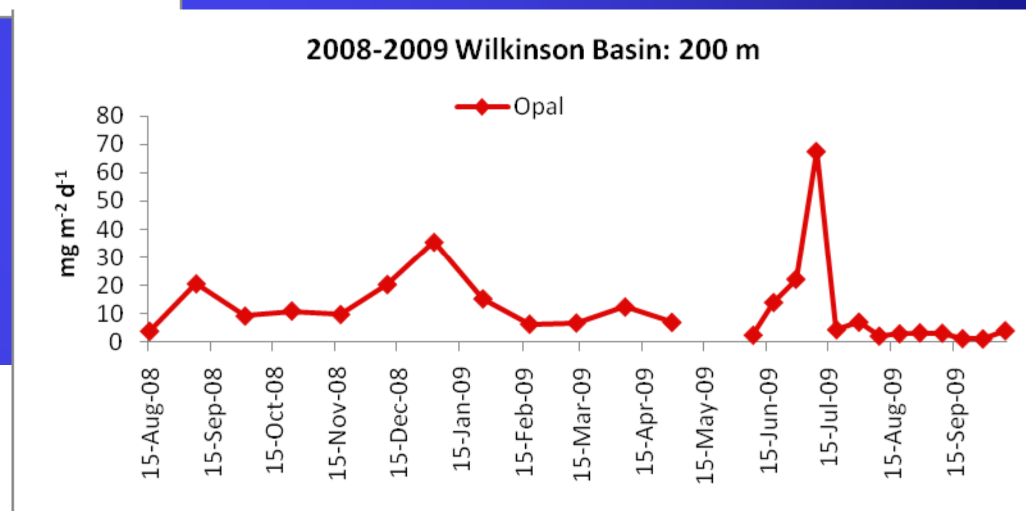


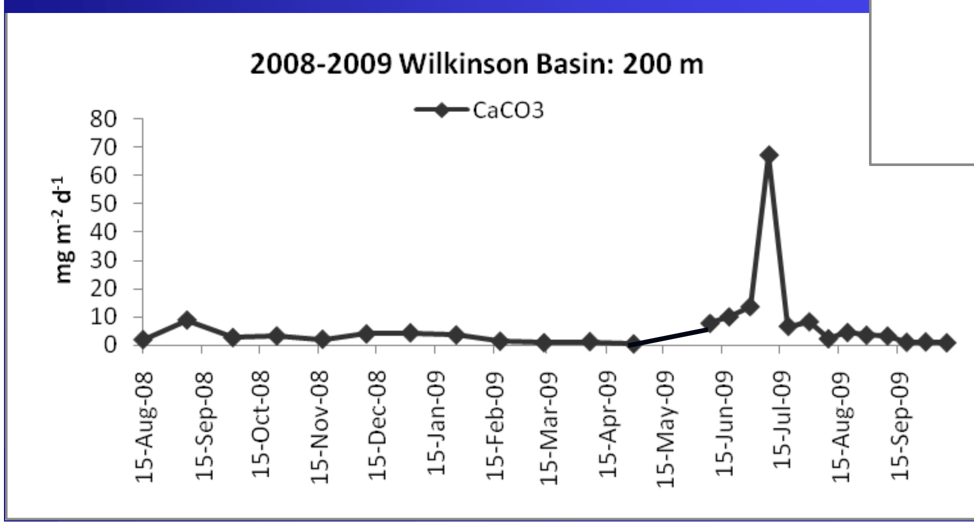


Salisbury and Vandemark, unpubl.; Pilskaln, unpubl.



Examples of POC and biogenic mineral resuspension fluxes measured in Gulf of Maine BNL.





Seasonal peaks in biogenic component fluxes in upper traps well above BNL typically reflected in BNL resuspension fluxes.

BNL particle properties:
from transmissometer, backscattering sensor & chl *a* fluorometer

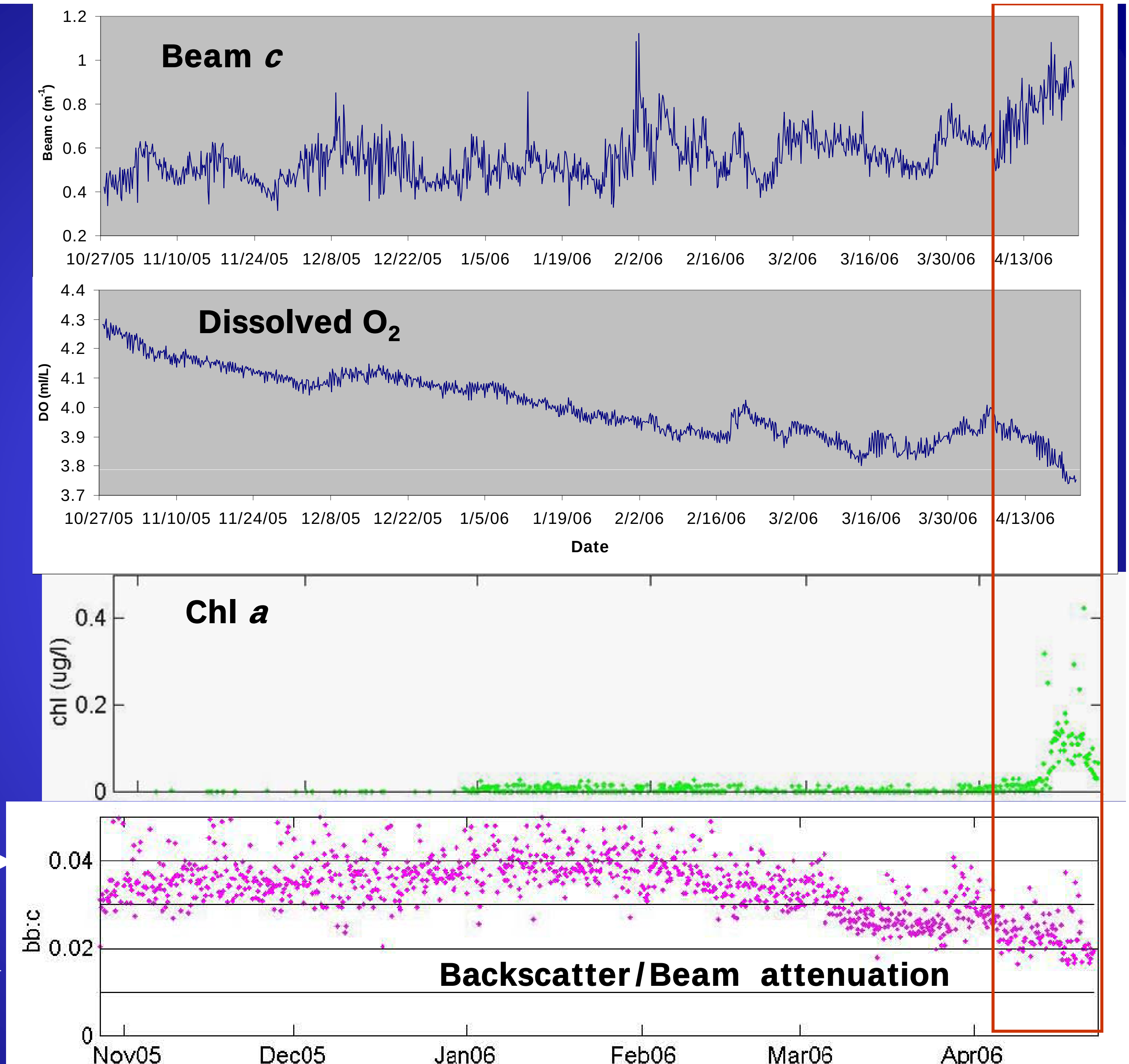
Oct 2005-Apr 2006 time-series
Jordan Basin, 254 m

*Increase in light attenuation coincident with decreasing DO and increase in particles of relatively higher organic content & higher [chl *a*]

Higher inorganic content →

Higher organic content →

(Based on Twardowski et al., 2001)



BNL organic carbon age and lability:

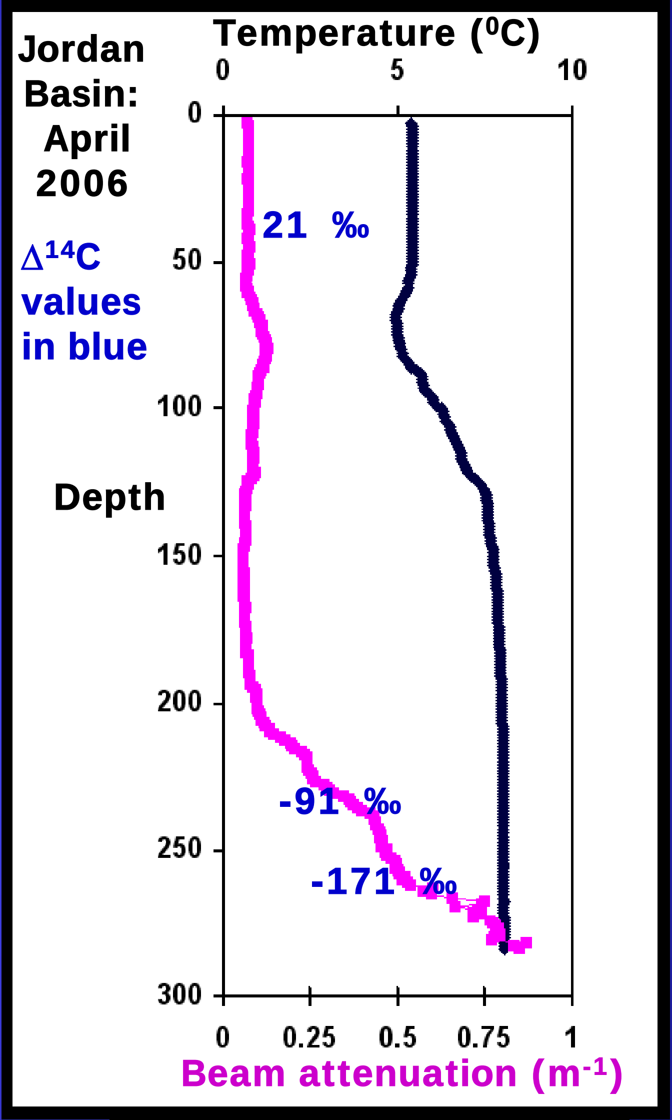
Refractory/Labile?

*Average BNL (and surface sediment) particulate organic carbon content = 3%

*BNL resuspension flux: Relatively low C/N ratio of 8

Pump-sampling and $\Delta^{14}C$ of Jordan Basin suspended POC April 2006:

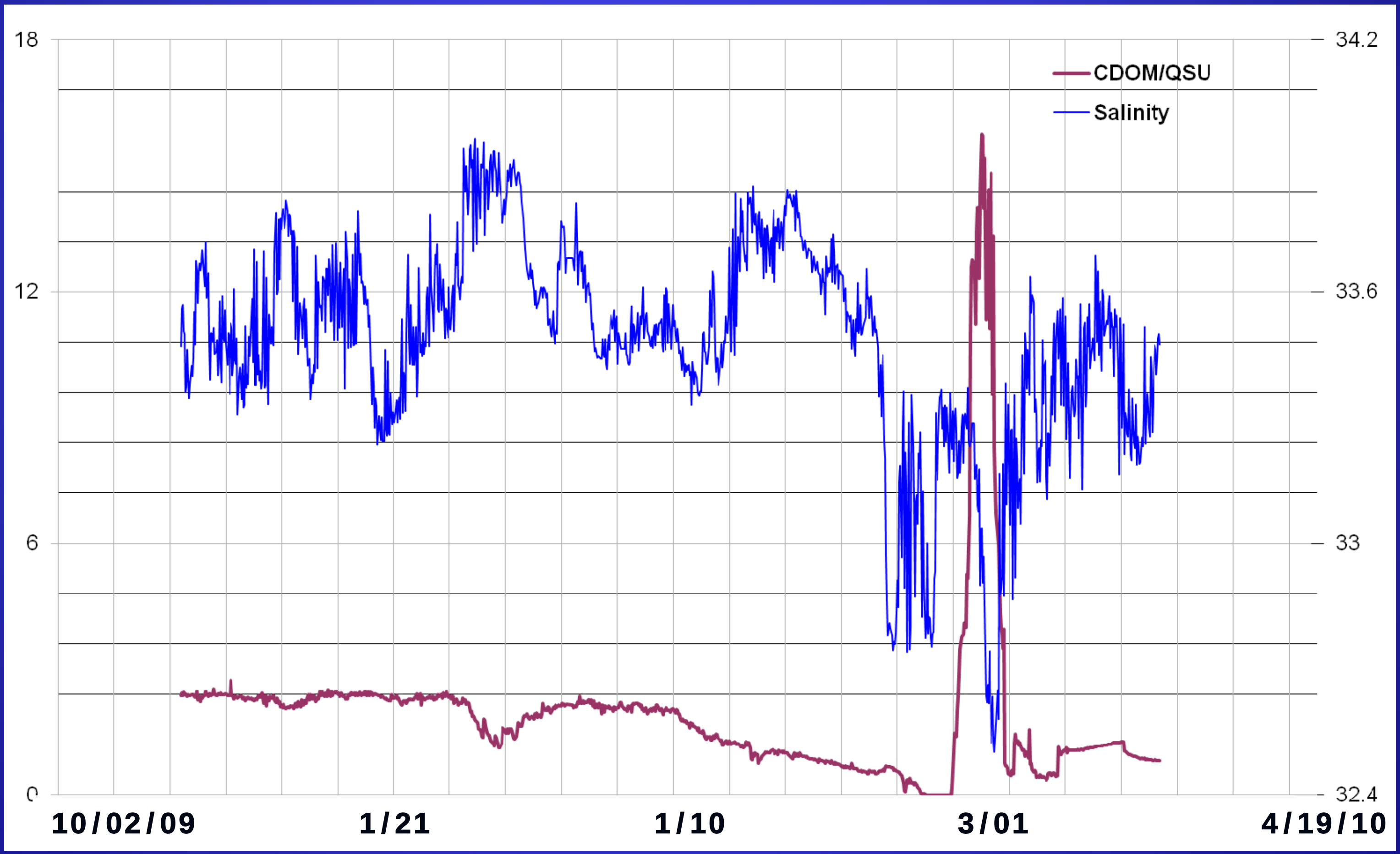
Mixed POC sources of aged carbon from bottom sediments and younger planktonic carbon originating in upper water column (Hwang & Eglinton, unpubl.)



Sediment sample $\Delta^{14}C$ = -214 ‰

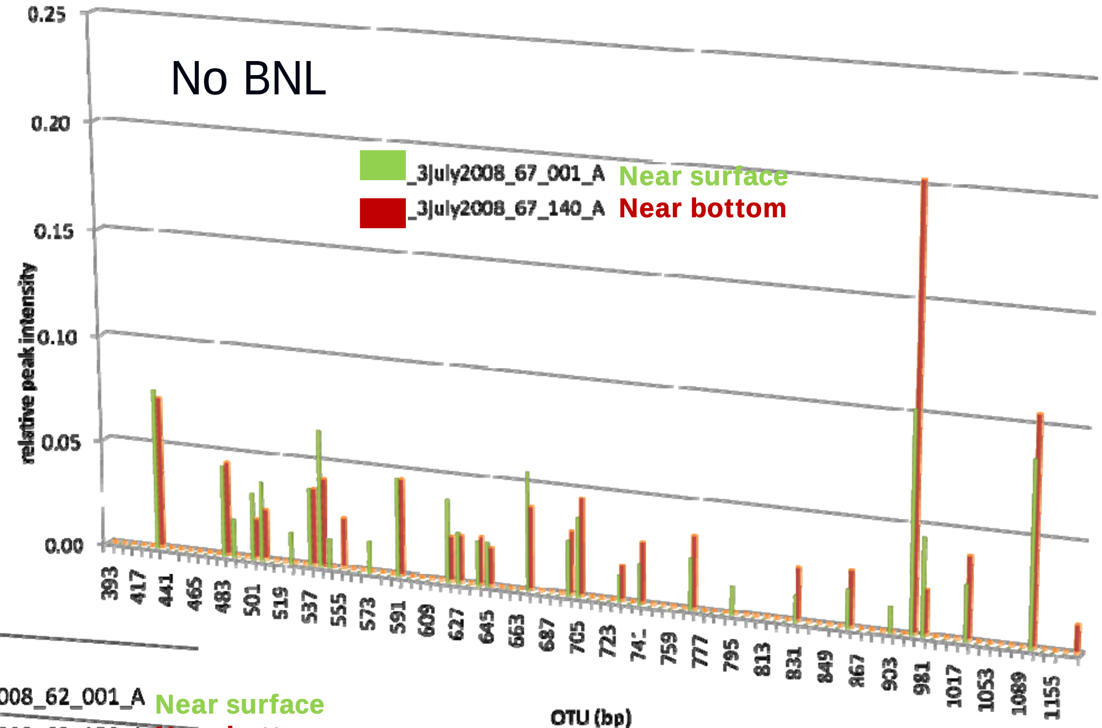
2009-2010 Wilkinson Basin BNL CDOM Time-Series: 200 m

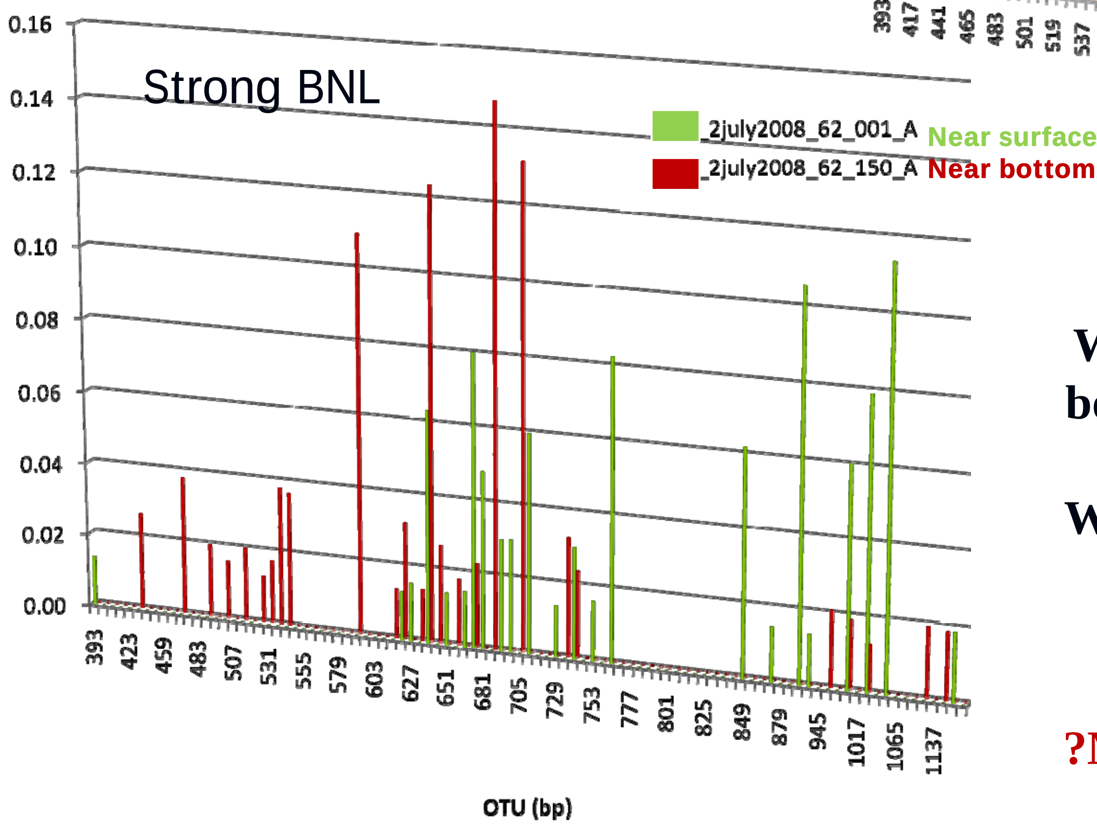
March 2010 input of fresh water to BNL reflected in large CDOM spike from typically low values of higher salinity water.



DNA/PCR (polymerase chain reaction) analyses for microbial community composition (8 stations, 41 samples). OTU = Operational taxonomic unit.

Free-living and attached bacteria in BNL (no surprise).





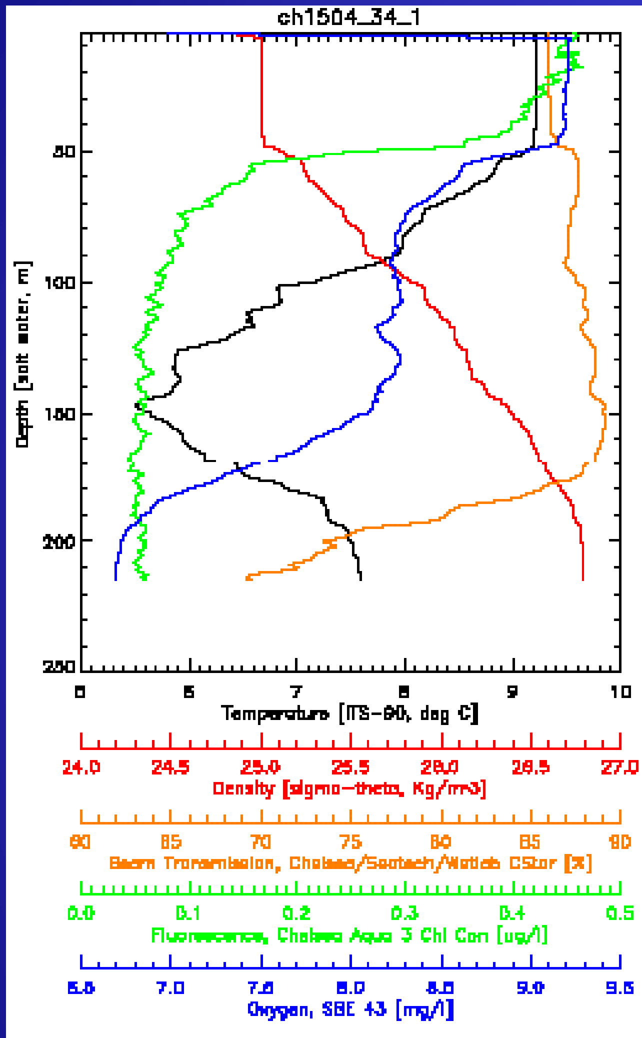
Intriguing results:

Where BNL <u>absent</u>, surface and near-bottom bacterial communities similar.

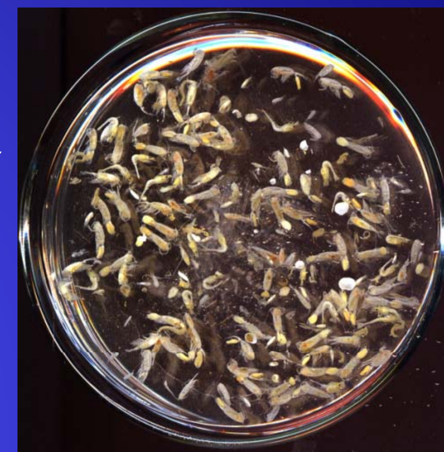
Where BNL <u>present</u>, surface and near-bottom communities distinctly different.

?More denitrifiers when BNL present?

In the deeper Gulf of Maine basins→ decrease in dissolved oxygen associated with benthic nepheloid layer.



Macrozooplankton from low O_2 BNL in Eastern Gulf of Maine

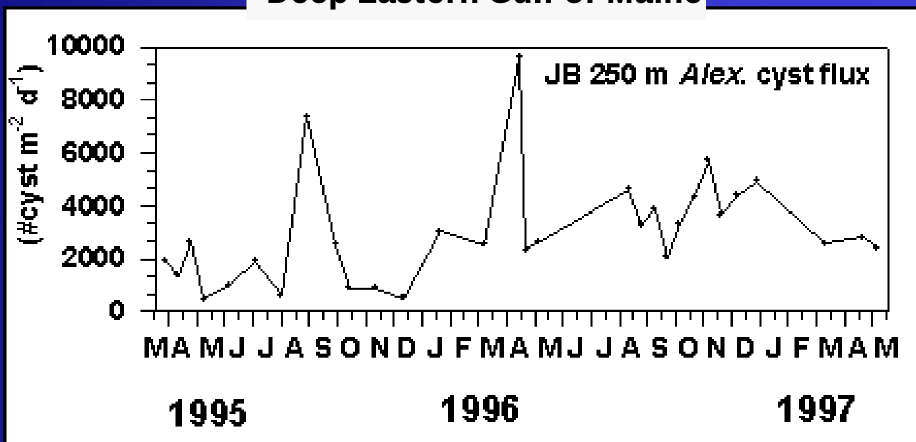


Biological O_2 consumption in BNL and oxidation of resuspended sedimentary reduced compounds: Supported by Christensen benthic fluxes/Packard respiratory ETS/Townsend et al., 1992 BNL biological data.

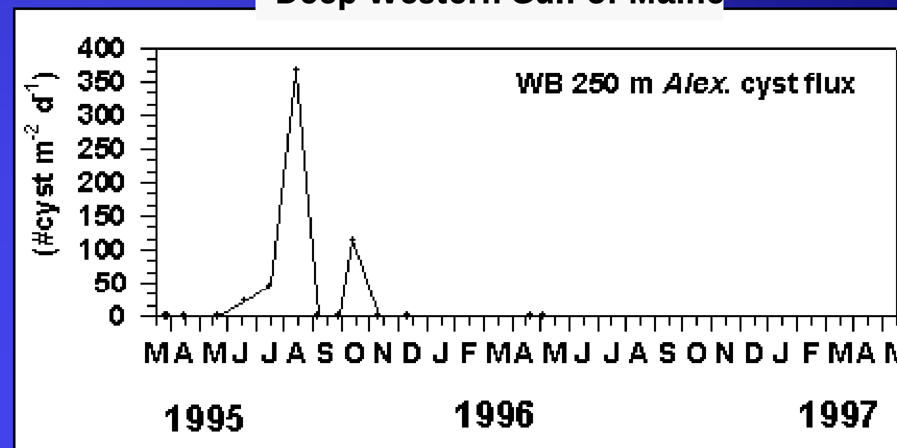
Abundant biological component in Gulf BNL: toxic dinoflagellate *Alexandrium* cysts.

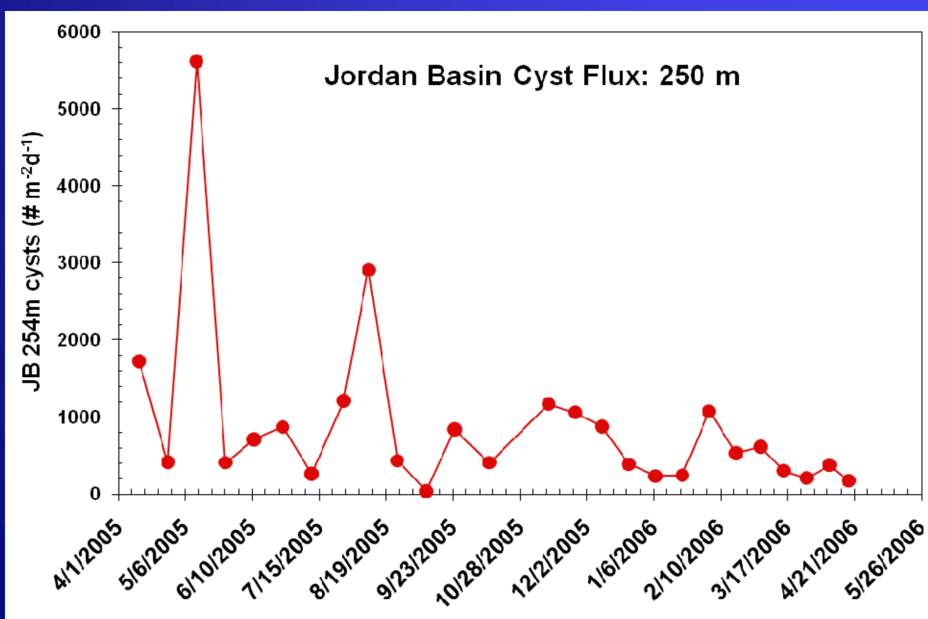
Cyst size: 50 x 100 μm (from Kirn et al., 2005)

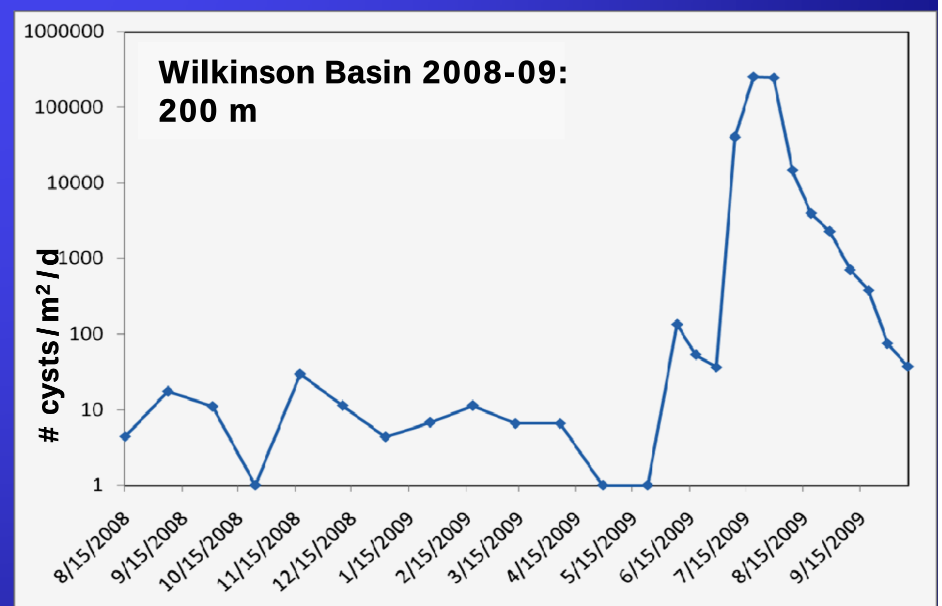
Deep Eastern Gulf of Maine



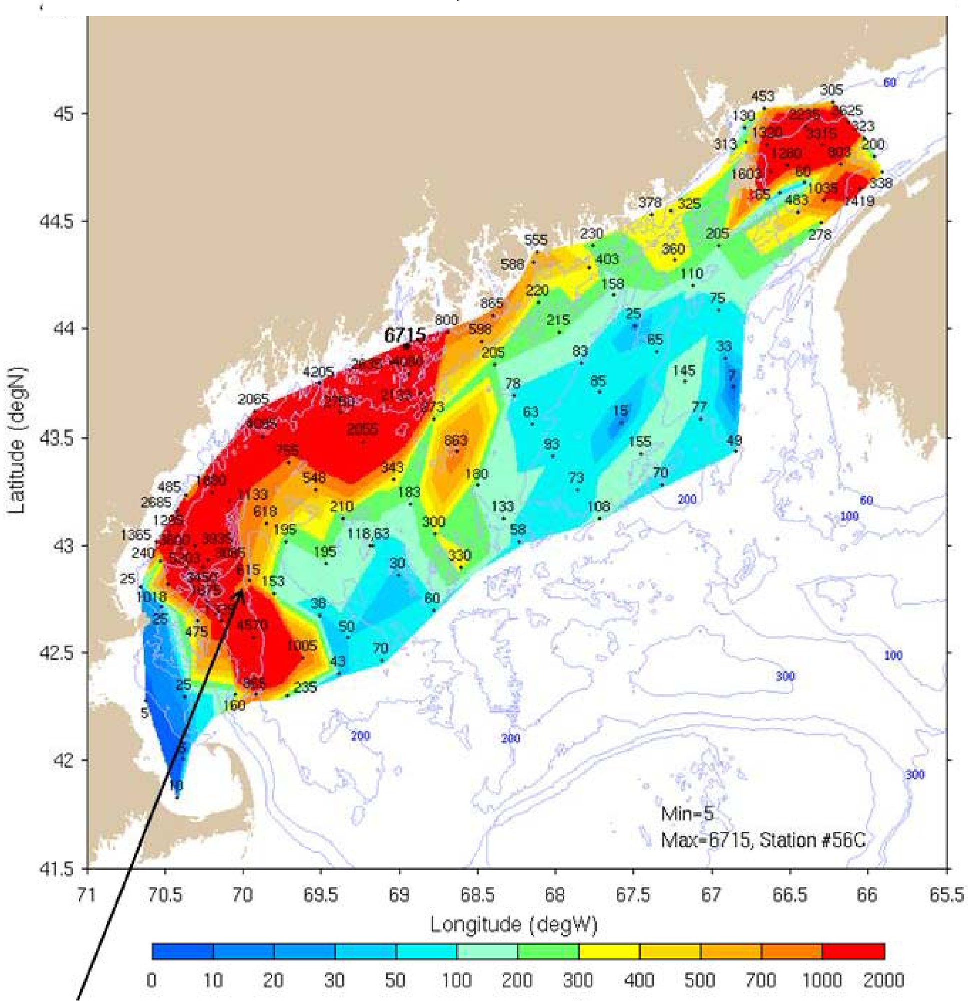
Deep Western Gulf of Maine







Surface sediment (0-1 cm) *Alex.* cyst counts, Oct. 2009



Location of 2008-2010 Wilkinson basin subsurface time-series traps &extremely high cyst resuspension fluxes

Anderson and Keafer, unpubl.

Gulf of Maine ongoing work:

Gulf BNL offers natural laboratory to examine numerous biogeochem. and physical processes occurring in shelf-based, BNLs in general.

Mooring/ buoy-based data collection continuing thru –integrated ~2year data sets forthcoming.

Modeling of Gulf-wide BNL distribution and movement and address question of offshore transport to adjacent deep slope.

Conclusions:

Lateral movement of BNL indicated by comparison of trap resuspension fluxes, surface sediment cyst abundance and seasonal delivery from overlying water column.

BNL shows strong compositional relationships to seasonal upper water column biogenic fluxes and impacts of various fresh and saltwater inflows to Gulf.

50% of POC in BNL resuspension fluxes: 50% POC, 25% opal, less than 10% $CaCO_3$ originates in upper water column.

So check out your local BNL—may surprise you!

Thanks to NOAA RMRP and ECOHAB programs and to many past and present Gulf of Maine-iac colleagues.