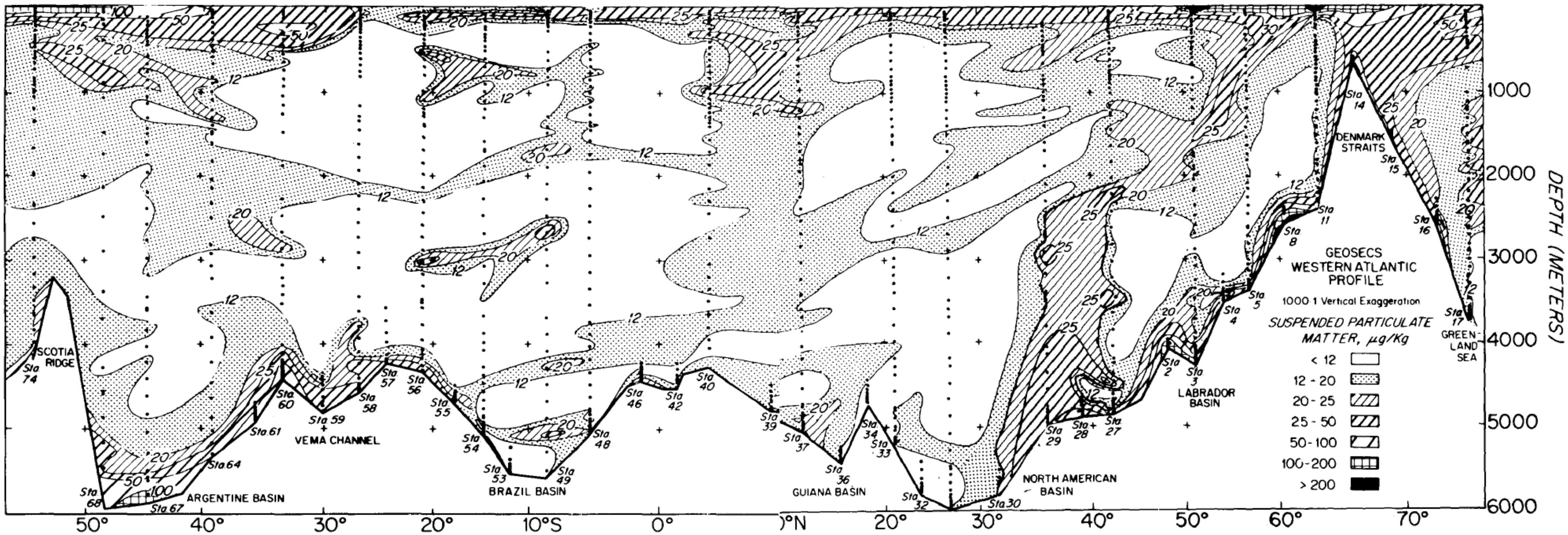
Bottom and Intermediate nepheloid layers

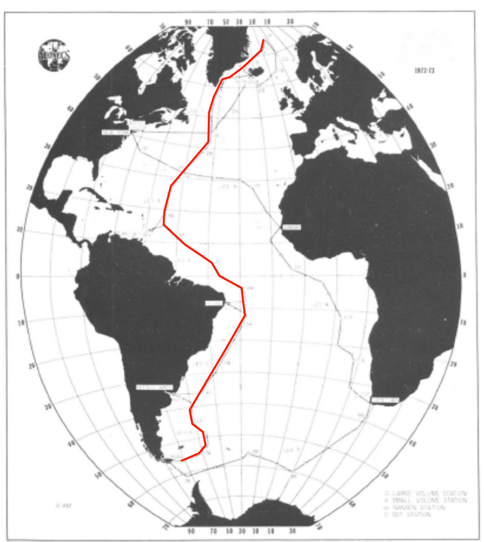
Michiel Rutgers van der Loeff and Sven Kretschmer

3rd GEOTRACES Data-Model Synergy Workshop
Barcelona, 14-17 November, 2011

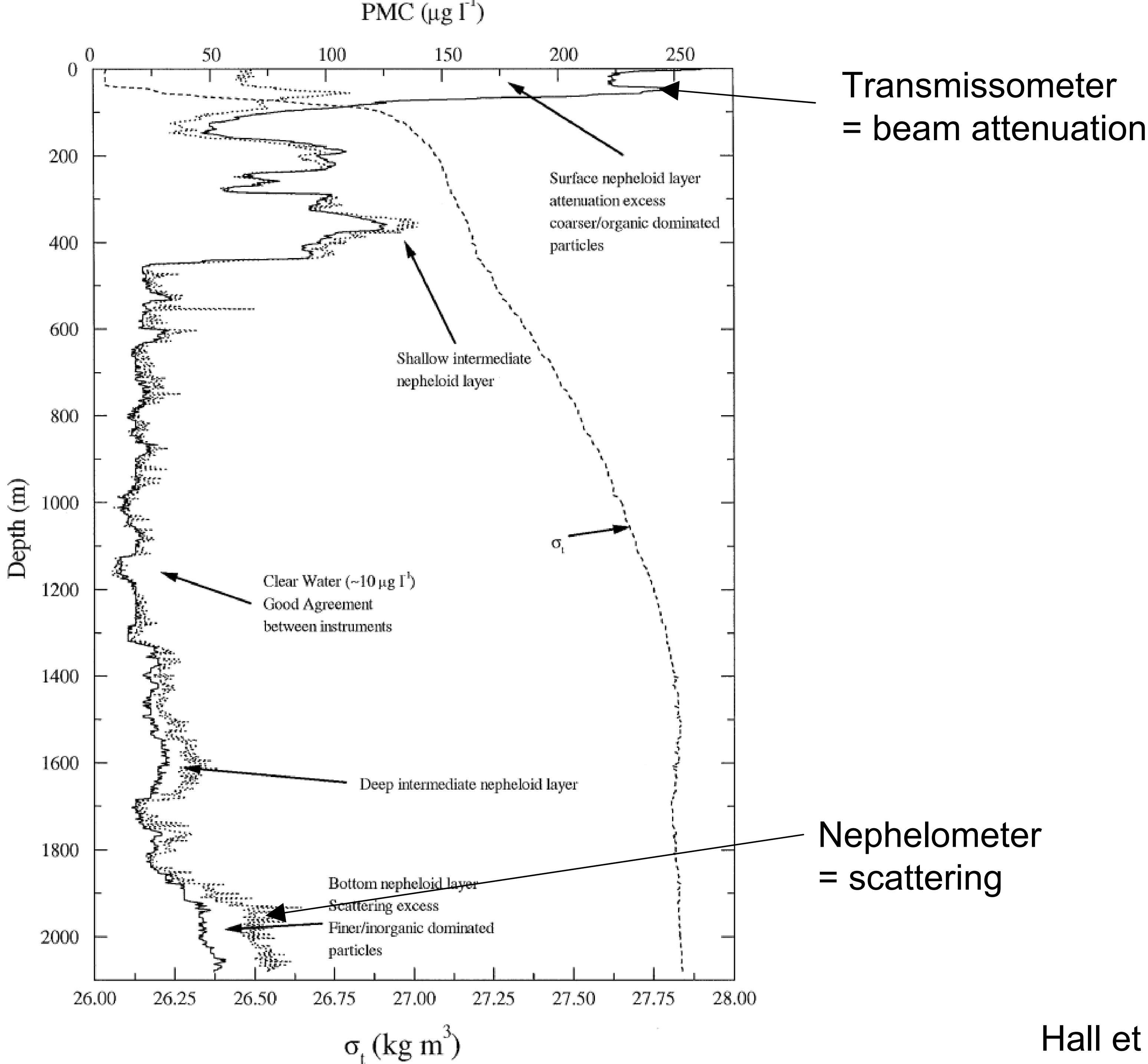
Suspended particulate matter during GEOSECS



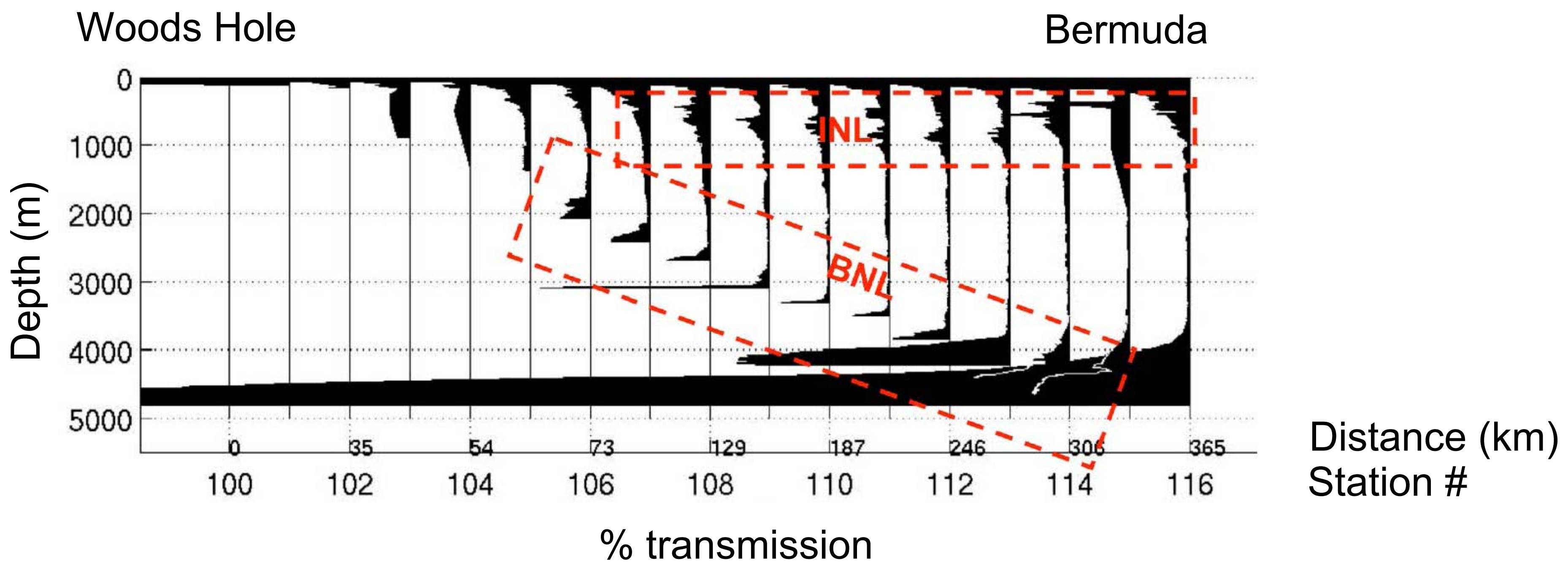
Longitudinal section of the dry weight of particulate matter in the western Atlantic Ocean.



Brewer et al., 1976



Hall et al., 2000



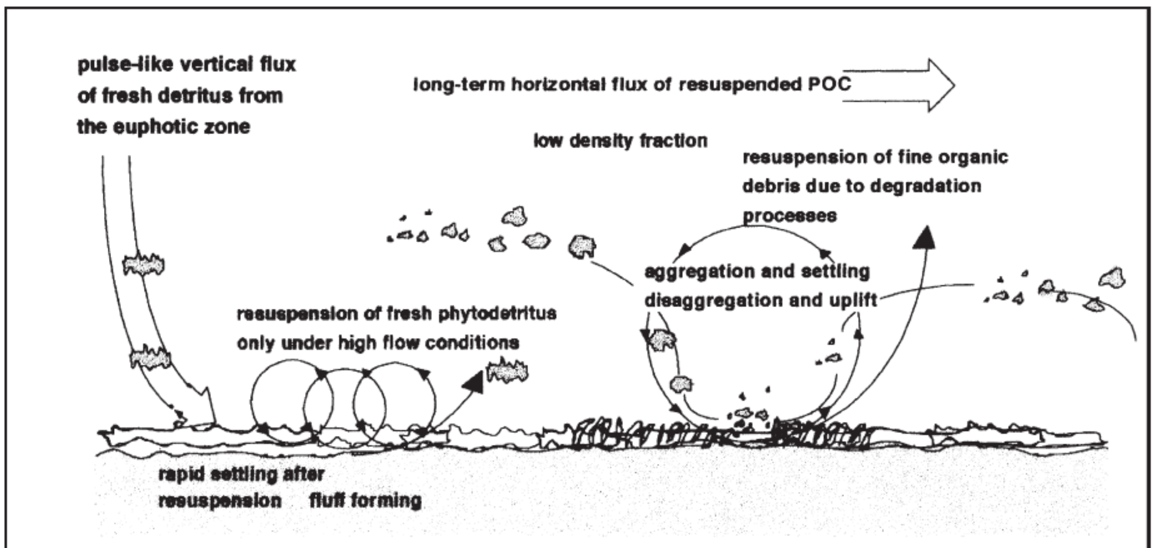
John Toole in
GEOTRACES Atlantic Report

BNL and INL

- Bottom Nepheloid layers:
  - Within a basin (local resuspension)
  - Long-range transport
  - Tracer transport and exchange
- Intermediate Nepheloid Layers

Local resuspension

- Generation, distribution, size spectra in BNL described by McCave (1984, 1986, 2001)
- Vertical mixing in bottom layer studied with ^{222}Rn. Vertical extent enhanced by detachment of bottom mixed layers

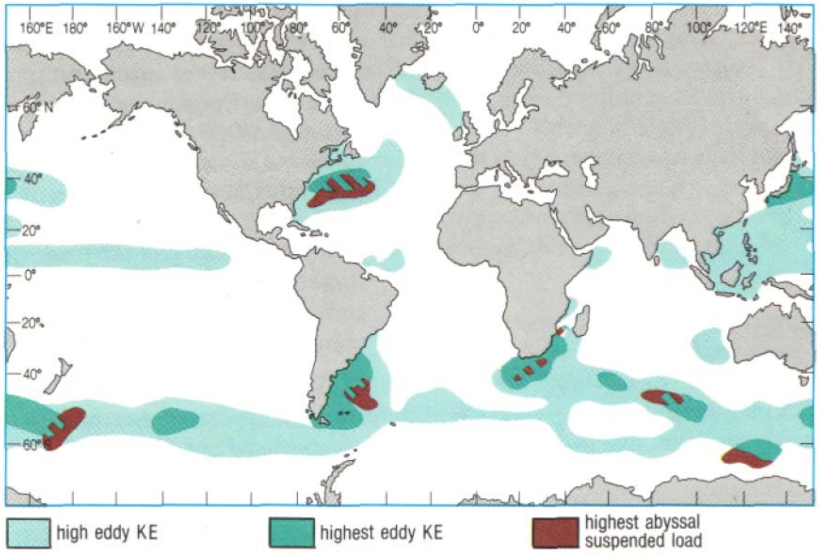


Settling and resuspension

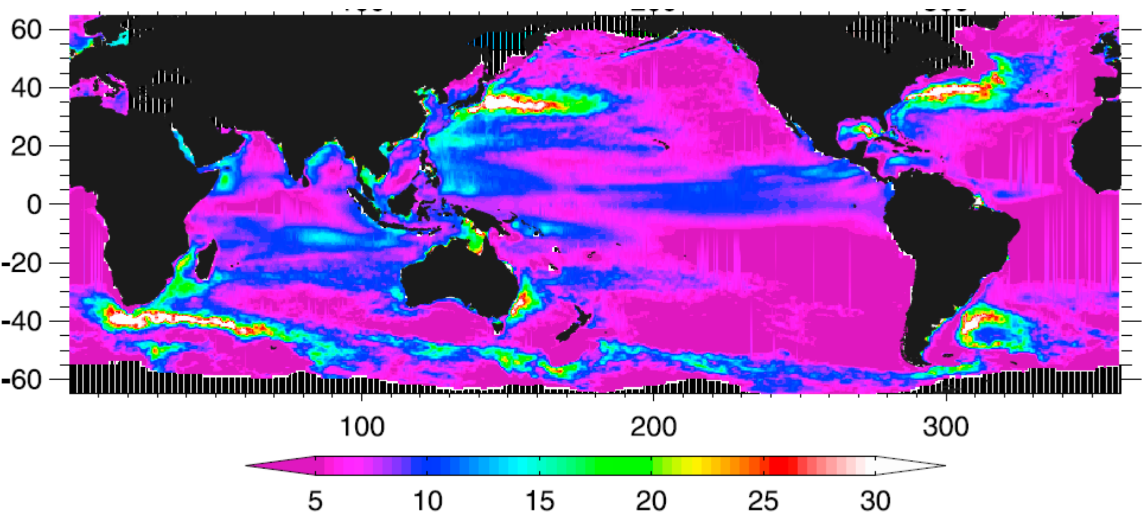
Phytodetritus pulses
Aggregation/Disaggregation
Faunal activities

Thomsen and van Weering 1998

Resuspension by high eddy kinetic energy



Open University based on Hollister and McCave 1984

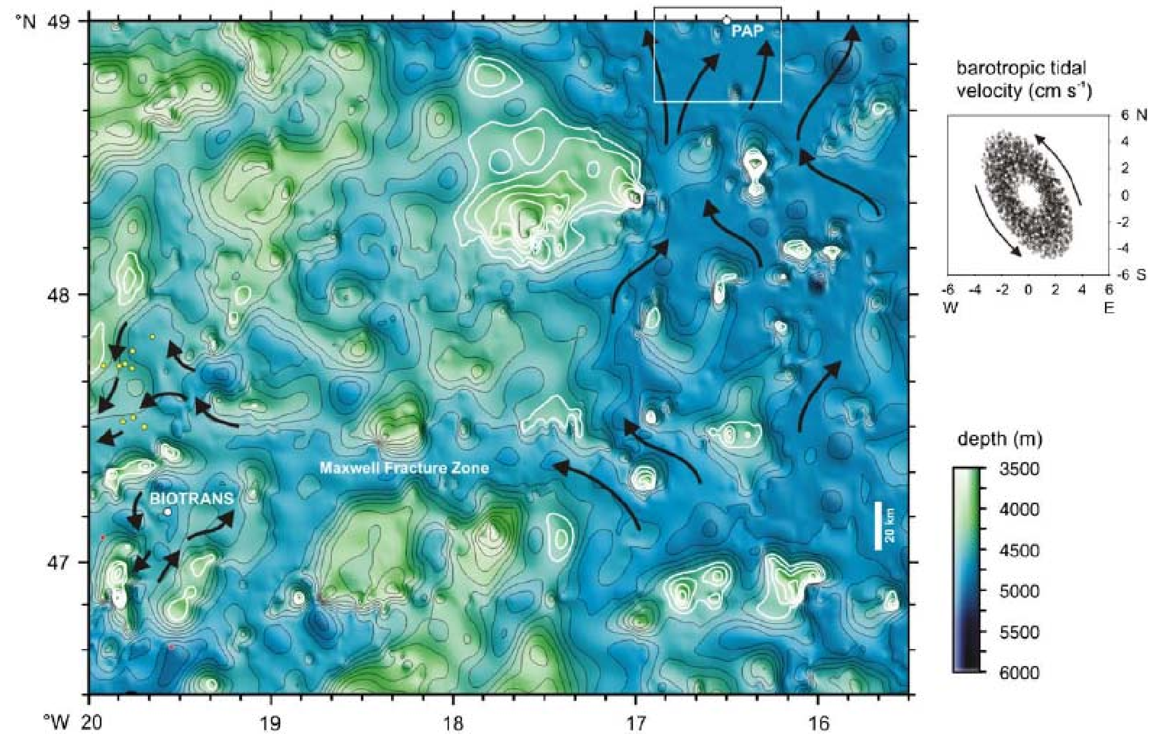


Standard deviation of sea surface height (in cm) from satellite altimeter data

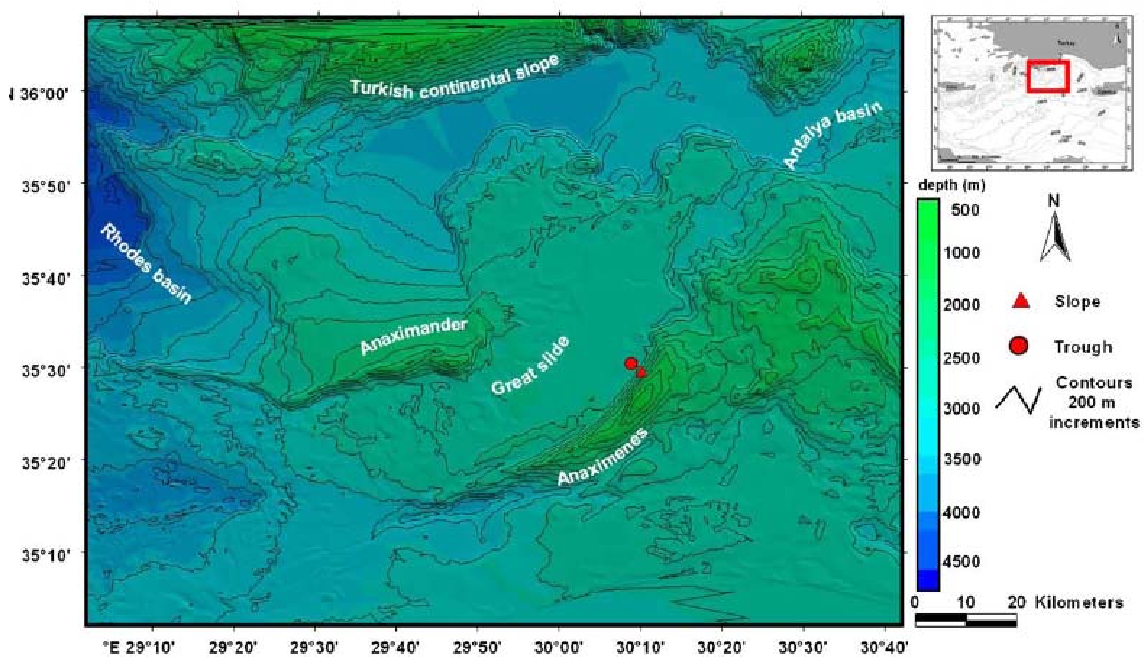
Lee-Lueng Fu, JGR, 2009

Resuspension by tides:

NE Atlantic

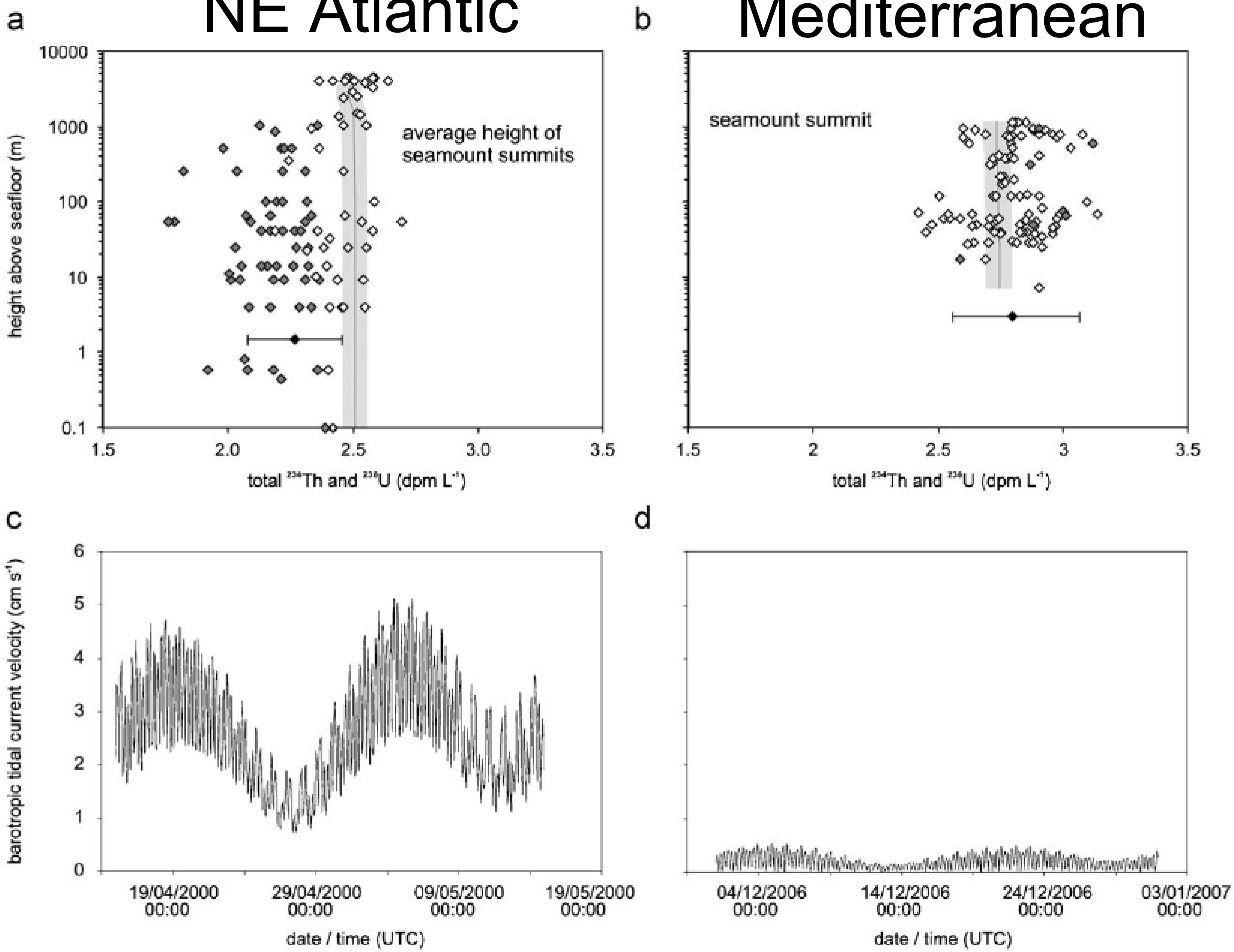


E. Mediterranean



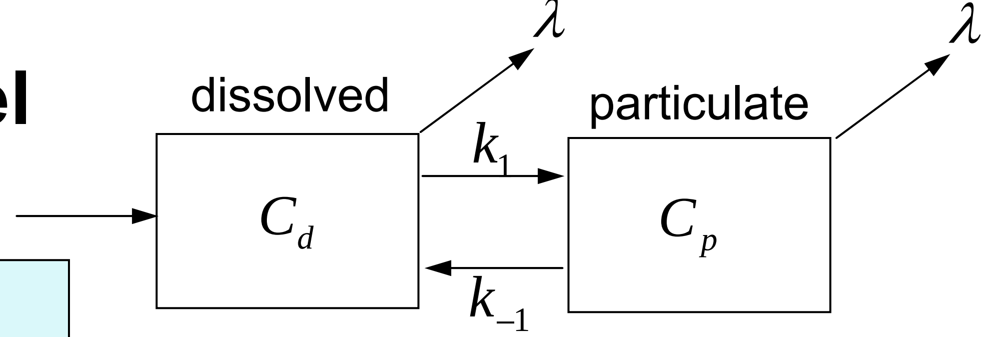
Turnewitsch et al., 2008
Peine et al., 2009

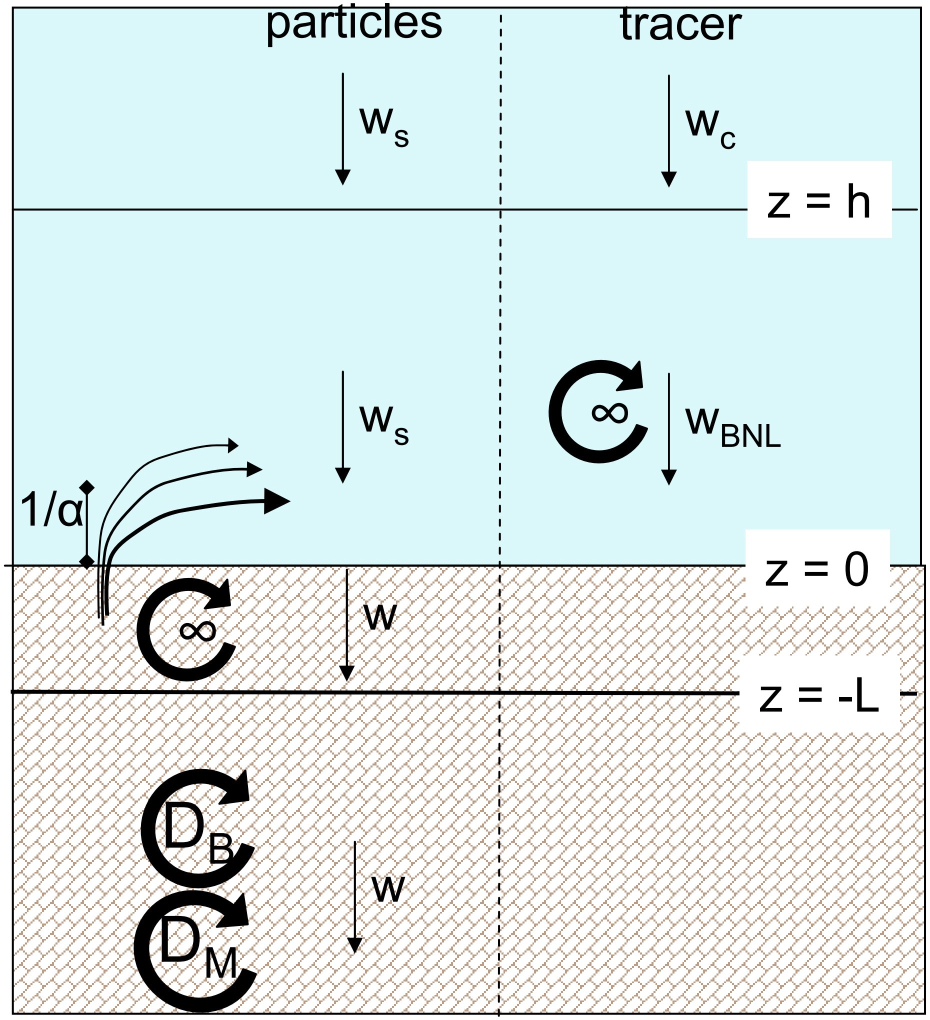
NE Atlantic Mediterranean

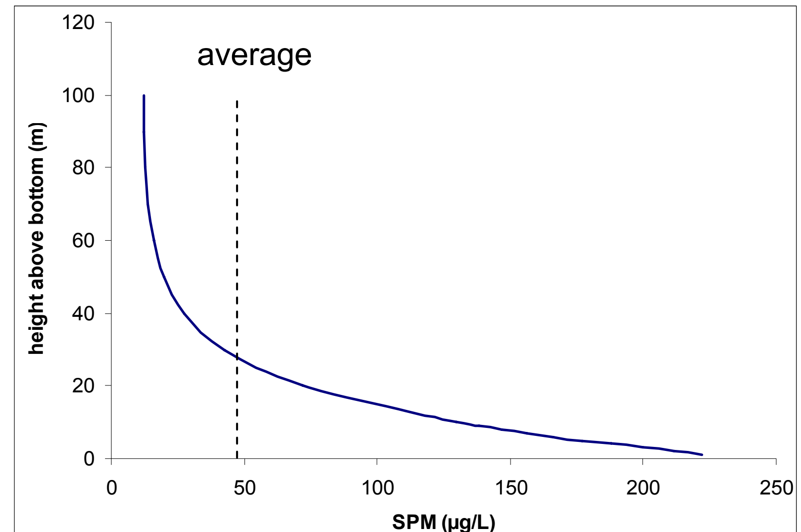


Peine et al., 2009

Resuspension model





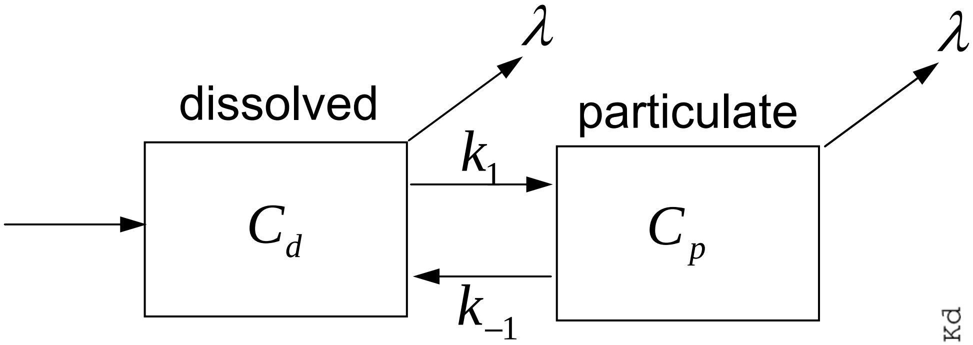


Apply to	Halflife (y)	Total activity BNL/clear water
^{234}Th	.07	0.86
^{228}Th	1.9	0.26
^{210}Pb	22.3	0.27
^{230}Th	75400	1.45

Bacon and RvdL, 1989; Boudreau, 1997; RvdL and Boudreau, 1997

Particle concentration effect

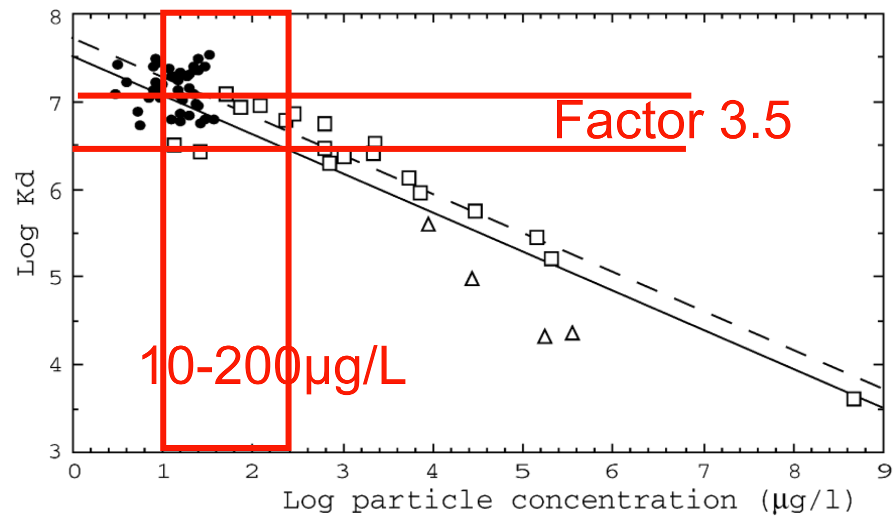
or: is K_d a constant?



Adsorption equilibrium exists when

$$\frac{C_p}{C_d} = \frac{k_1}{k_{-1} + \lambda}$$

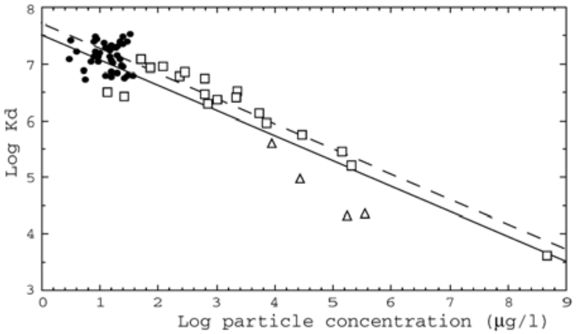
$$\frac{X}{C_d} = \frac{k_1}{P} \frac{1}{k_{-1} + \lambda} = K_d$$



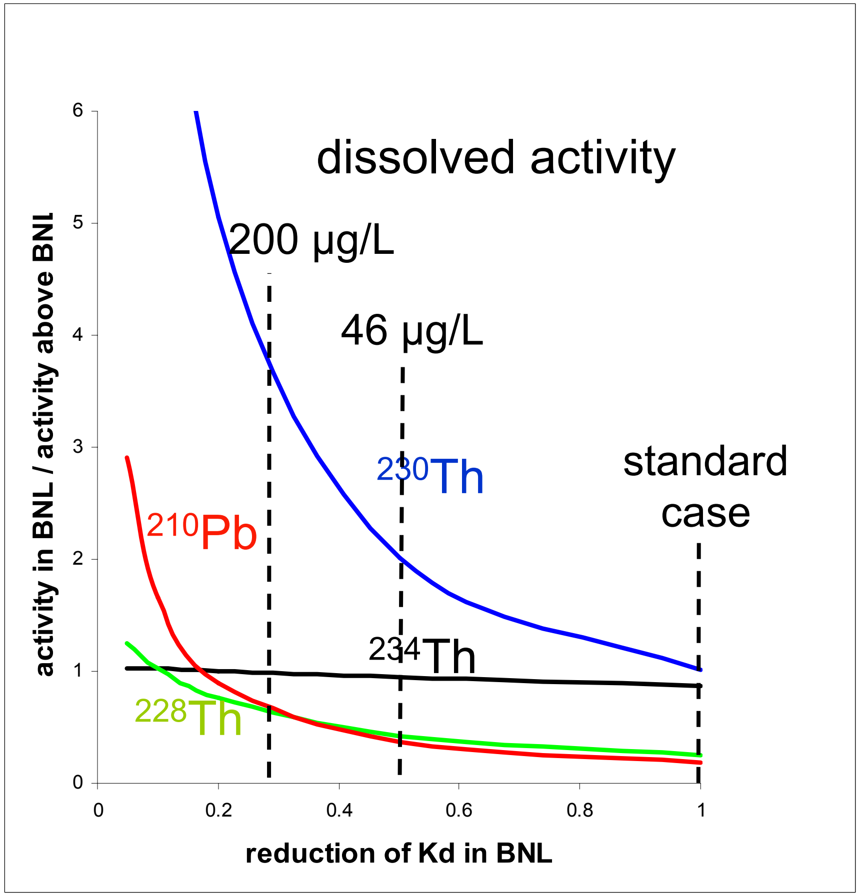
Henderson et al., 1999
based on Honeyman et al., 1988

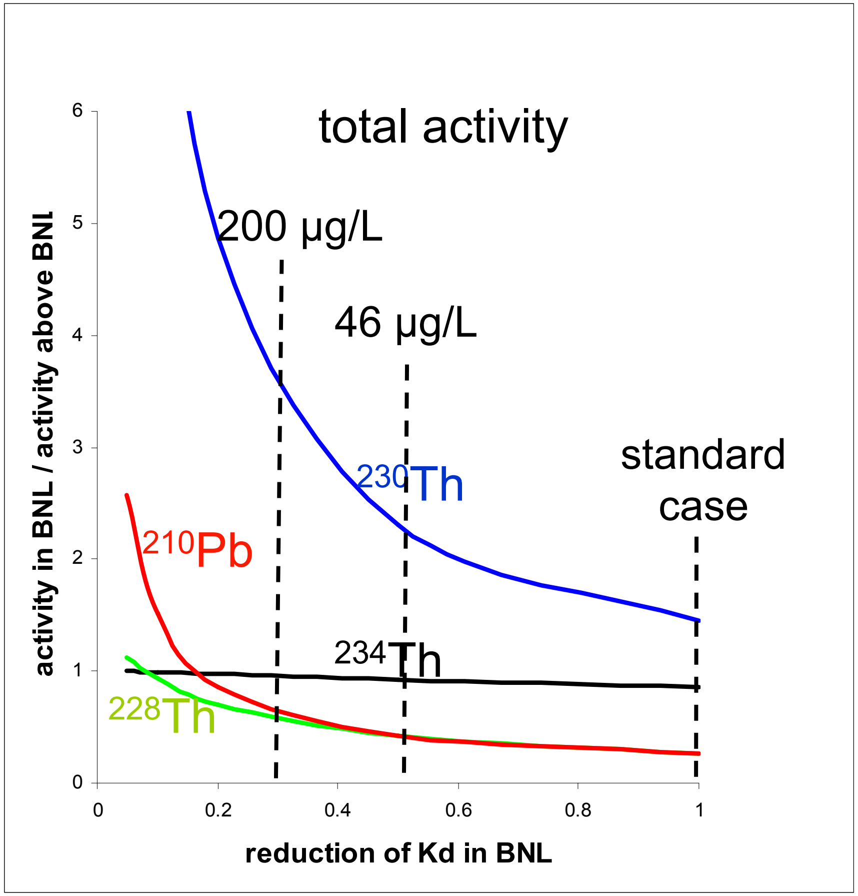
P = suspended load
X = activity per mass of particles
C_p = X.P =particulate activity
C_d = dissolved activity per mass of water
K_d = X/C_d = distribution coefficient

Particle concentration effect



Effect of reduction in Kd on scavenging in BNL

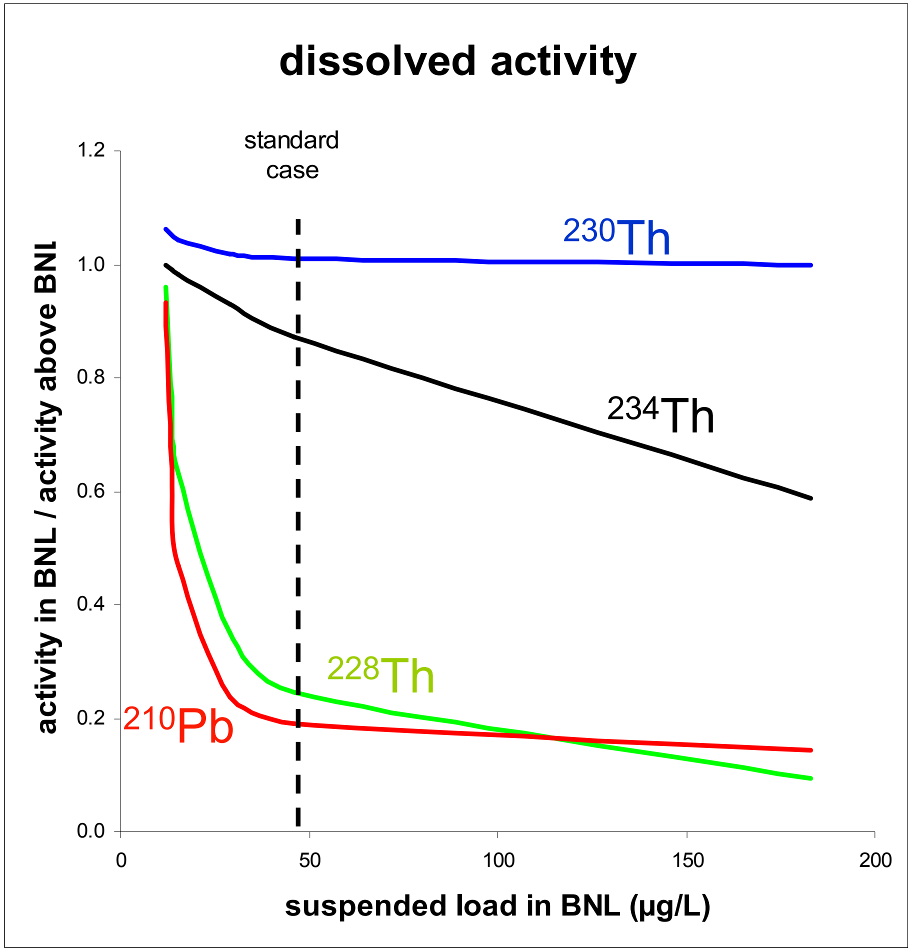


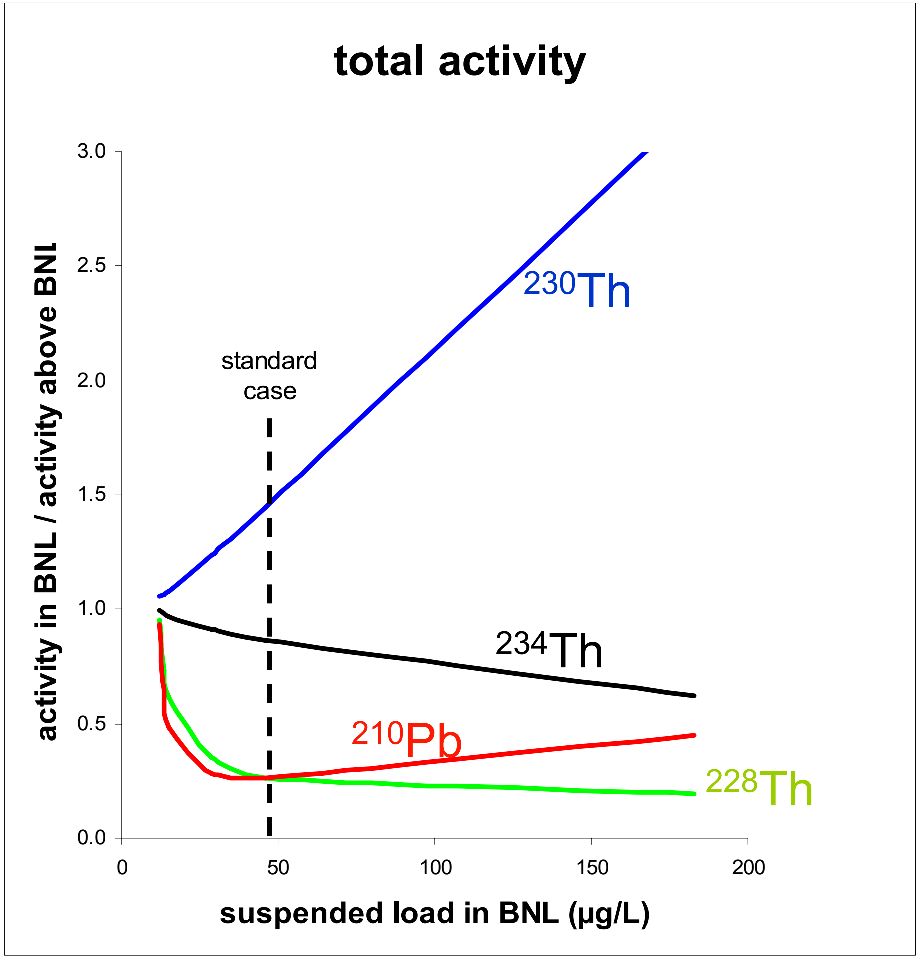


Half-lifes: ^{234}Th: 0.07y, ^{228}Th: 1.9y; ^{210}Pb: 22.3y; ^{230}Th: 75400y

Resuspension

Effect on scavenging in BNL

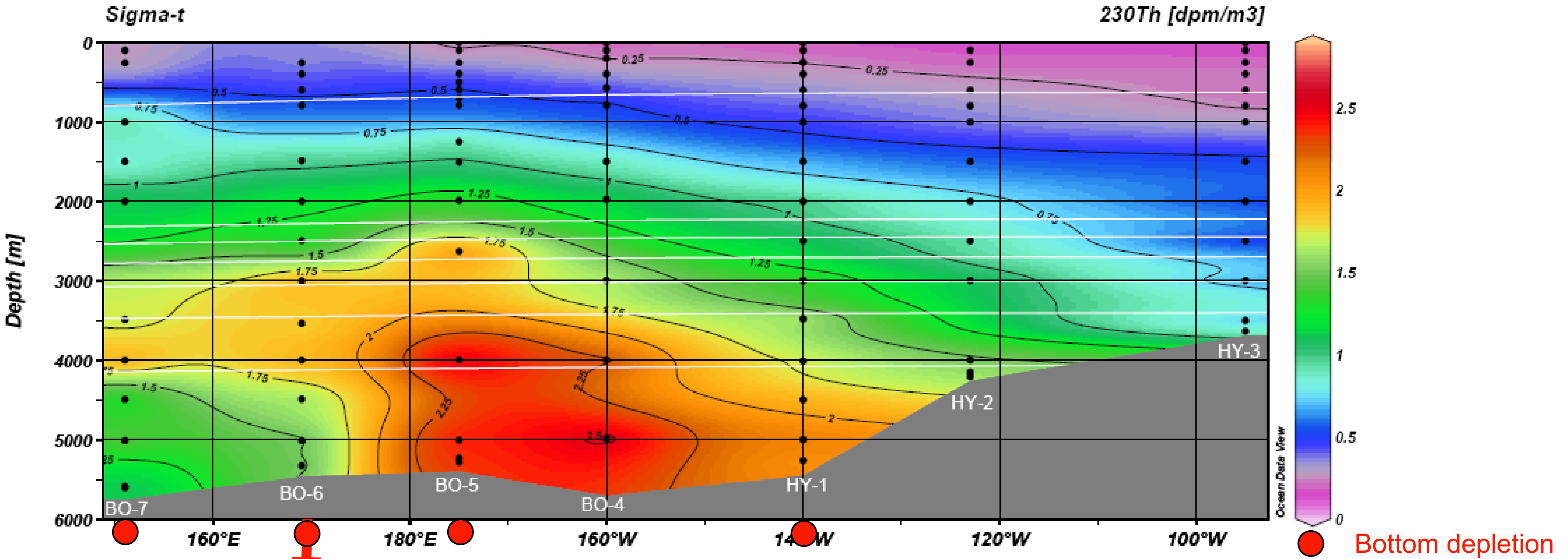


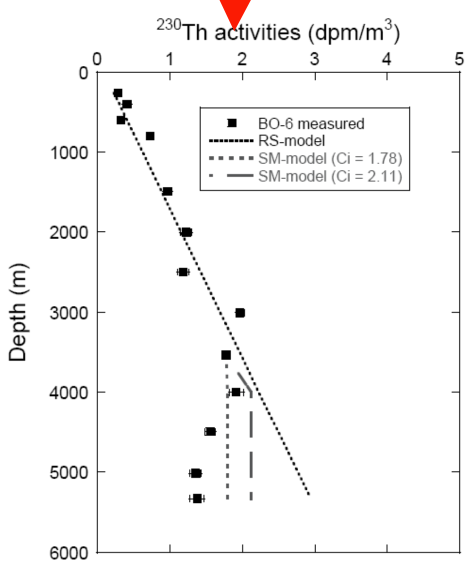


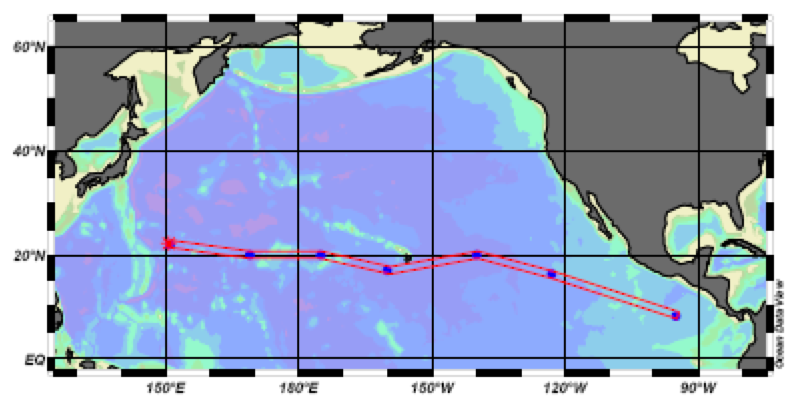
Conclusions on local resuspension

- Interaction between resuspension and bioturbation causes changes in dissolved component in BNL (scavenging)
  - if tracer decays within bioturbated zone
  - if Kd changes as a result of
    - Diagenetic changes (eg MnO_2 enrichment)
    - Particle dynamics (particle concentration effect, aggregation/disaggregation)

^{230}Th section in Pacific

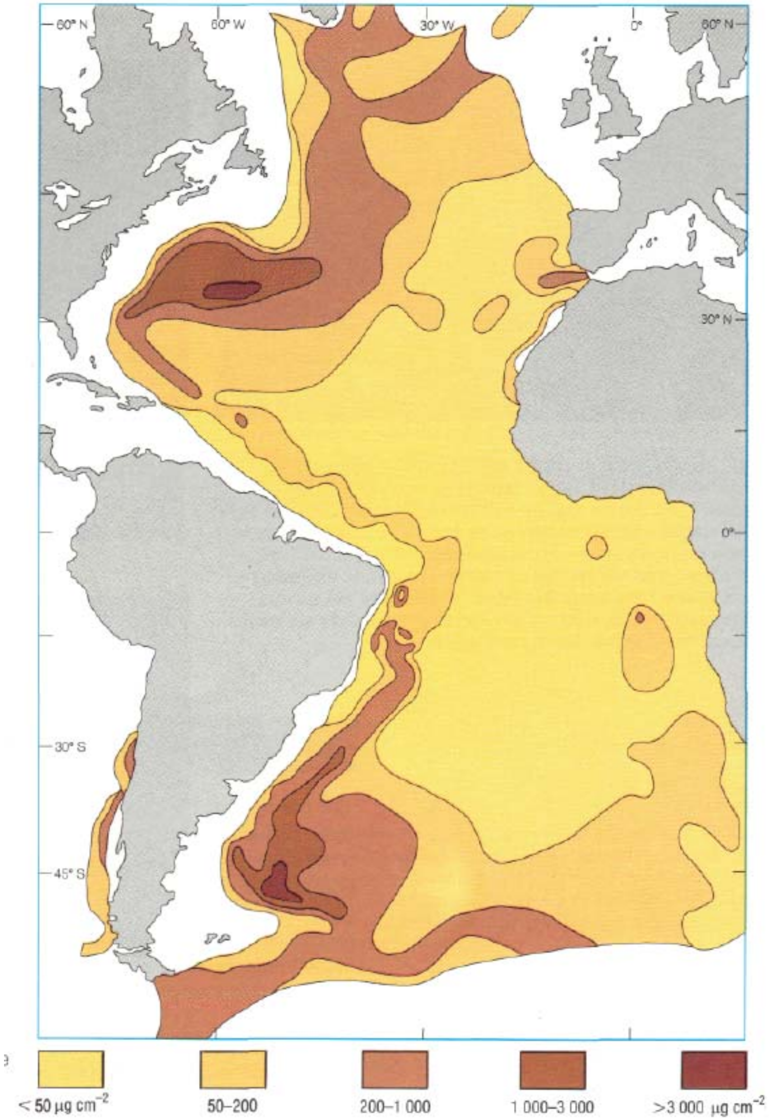






Okubo et al., EPSL, submitted

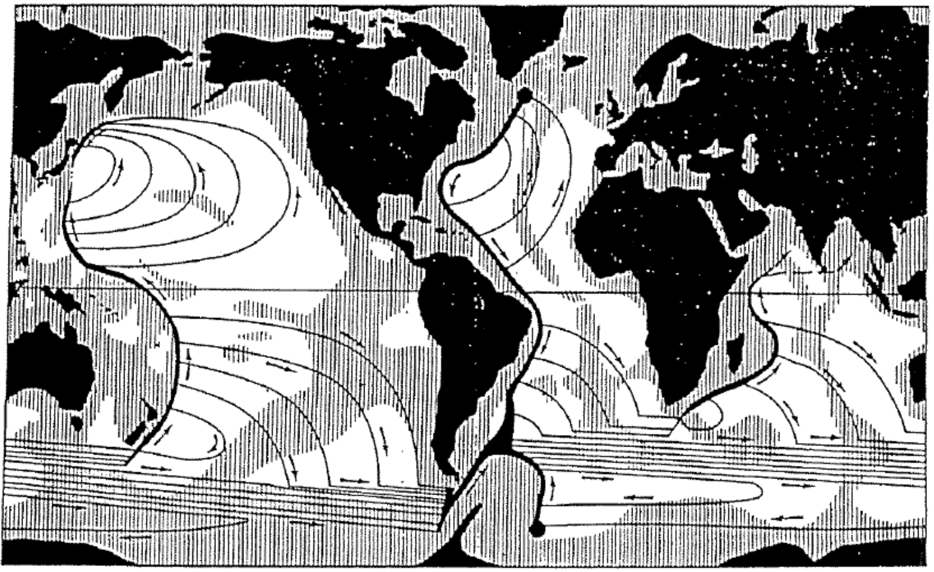
Long-range transport in BNL



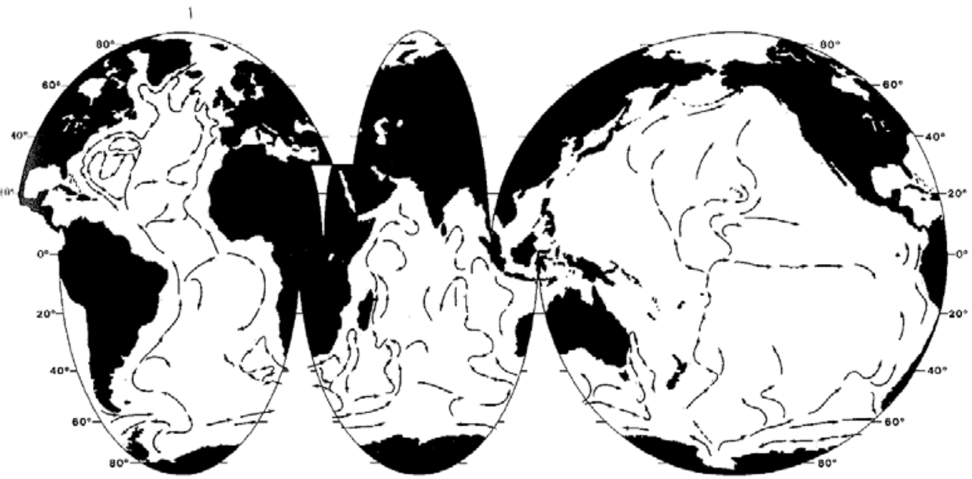
Suspended Particle Inventory in BNL
(in excess of clear water minimum)

Open University based on Biscaye and Eittreim 1977

Deep Western Boundary Currents

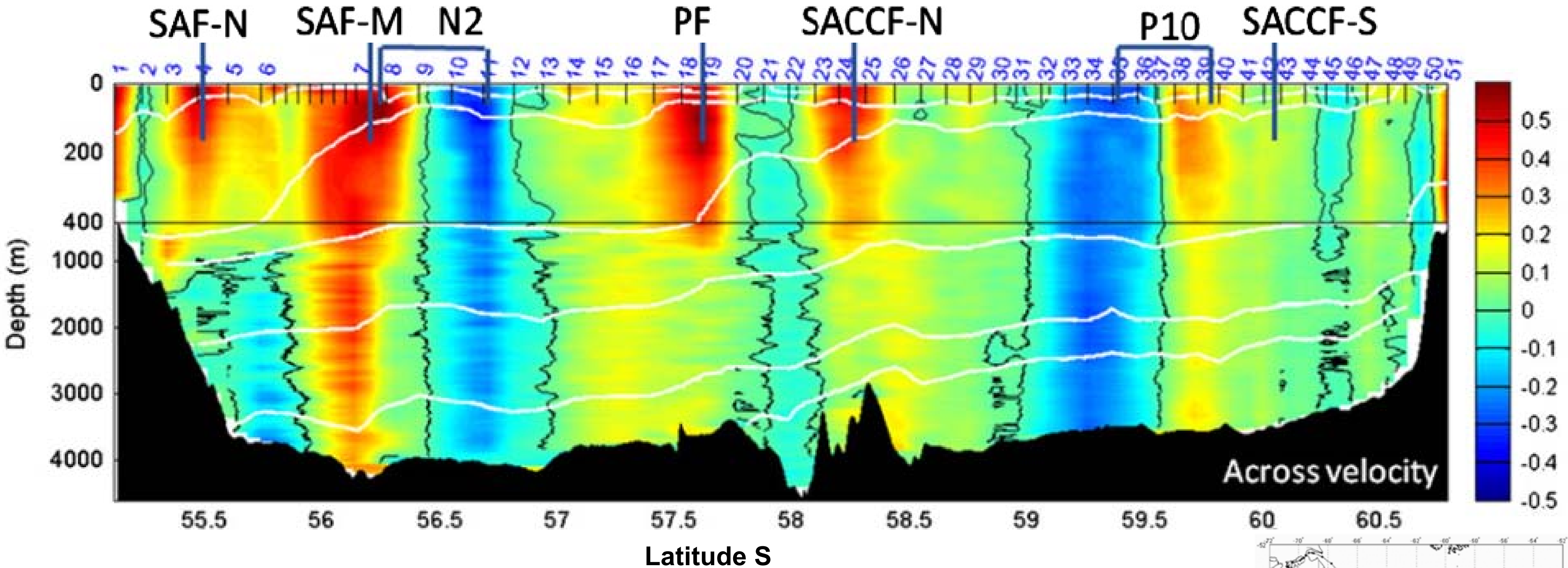


Stommel, 1958

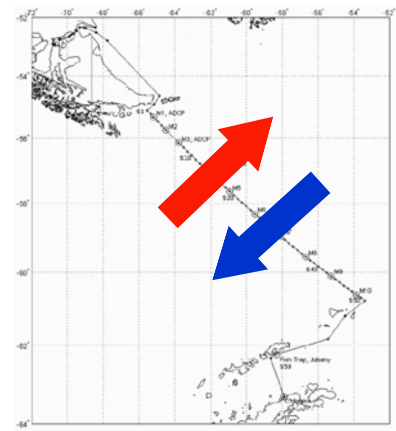


McCave 1986

Currents through Drake Passage

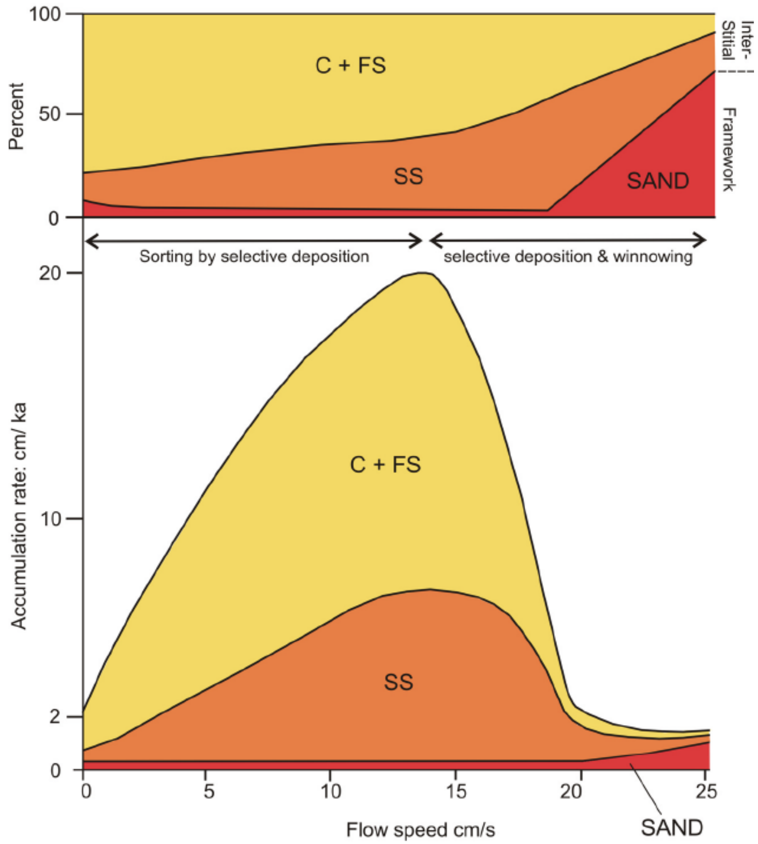


LADCP-velocity (m/s)



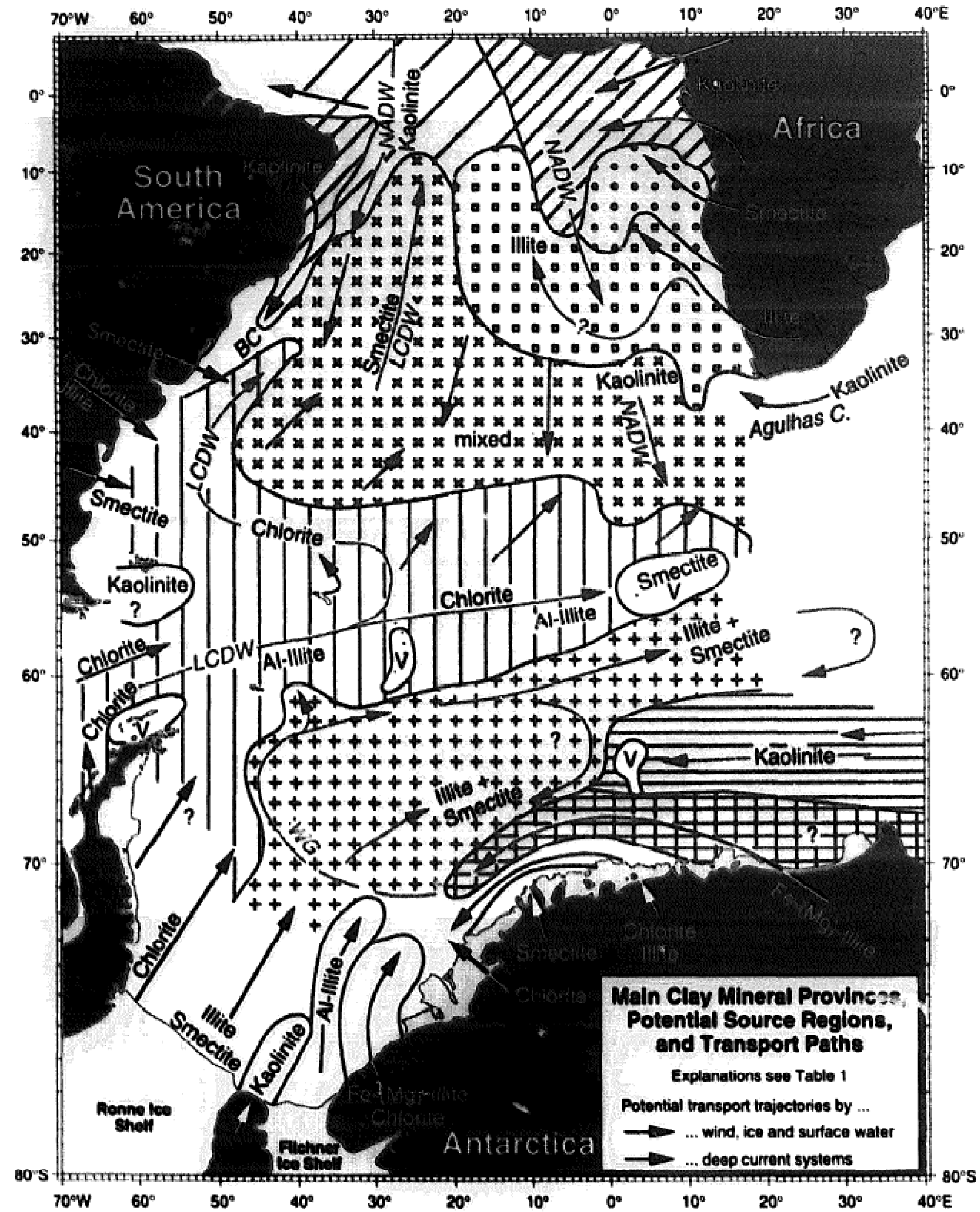
Renault et al., Provost et al., 2011

Resuspension and sorting in BNL



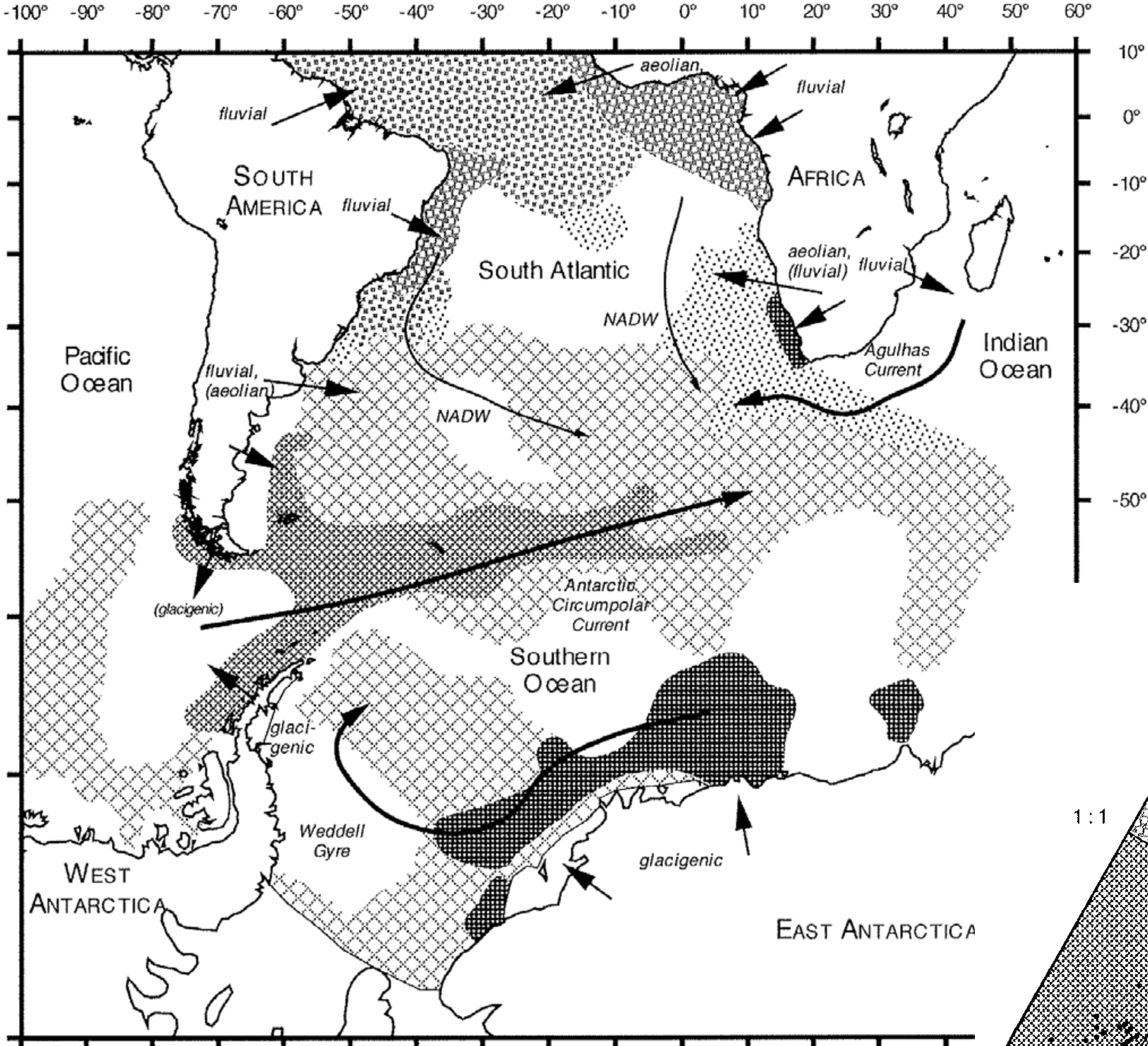
C+FS, clay and fine silt (<10 μm)
SS, sortable silt (10–63 μm)
SAND (>63 μm)

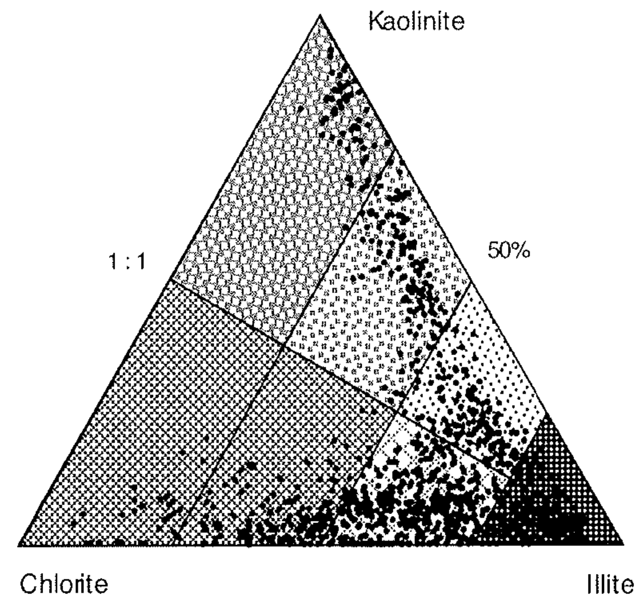
McCave and Hall, 2006



Petschik et al., 1996

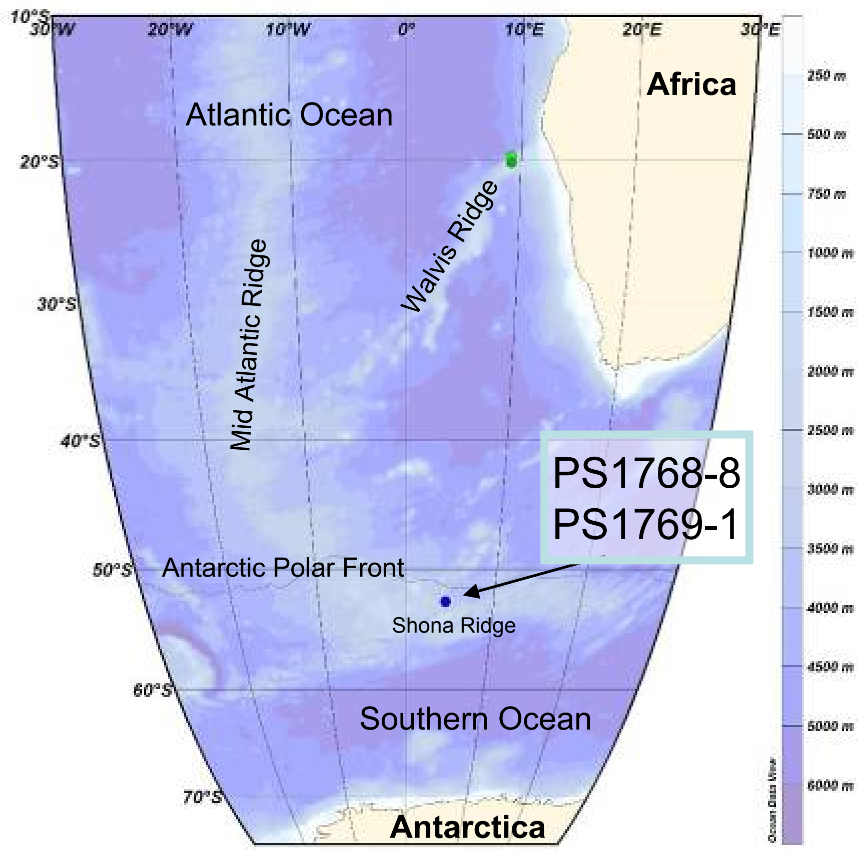
Clay mineral transport





Diekmann et al., 2004

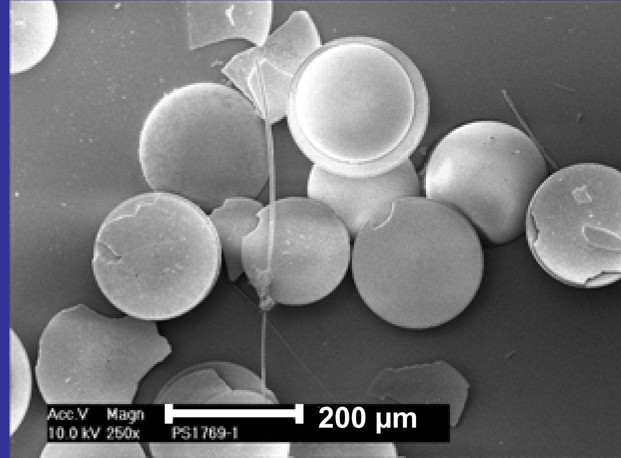
What is the effect of sorting on Transport of TEI on particles ?

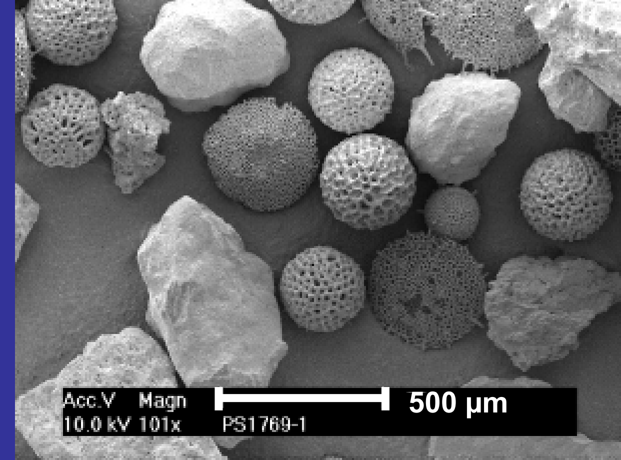


Cores studied by Kretschmer

PS1769-1
16 ka

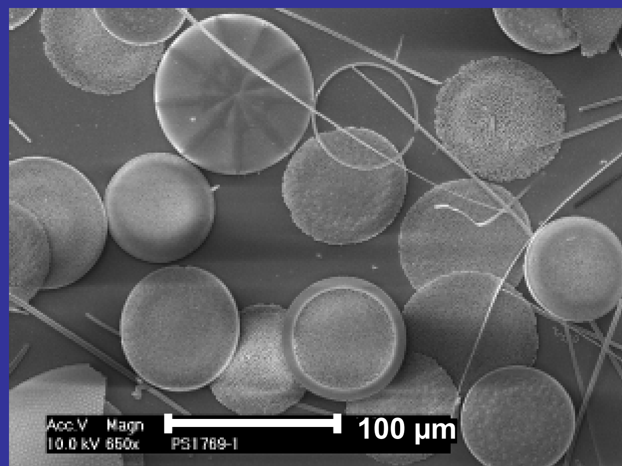
> 125µm
slowly settling





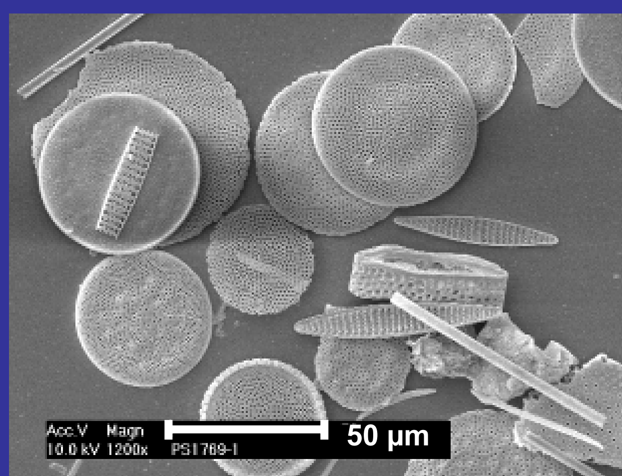
> 125µm
fast settling

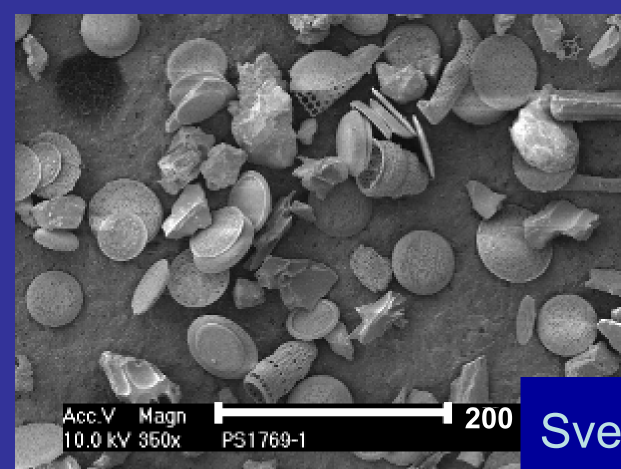
63-125 µm
slowly settling



63-125 µm
fast settling

20-63 µm
slowly settling

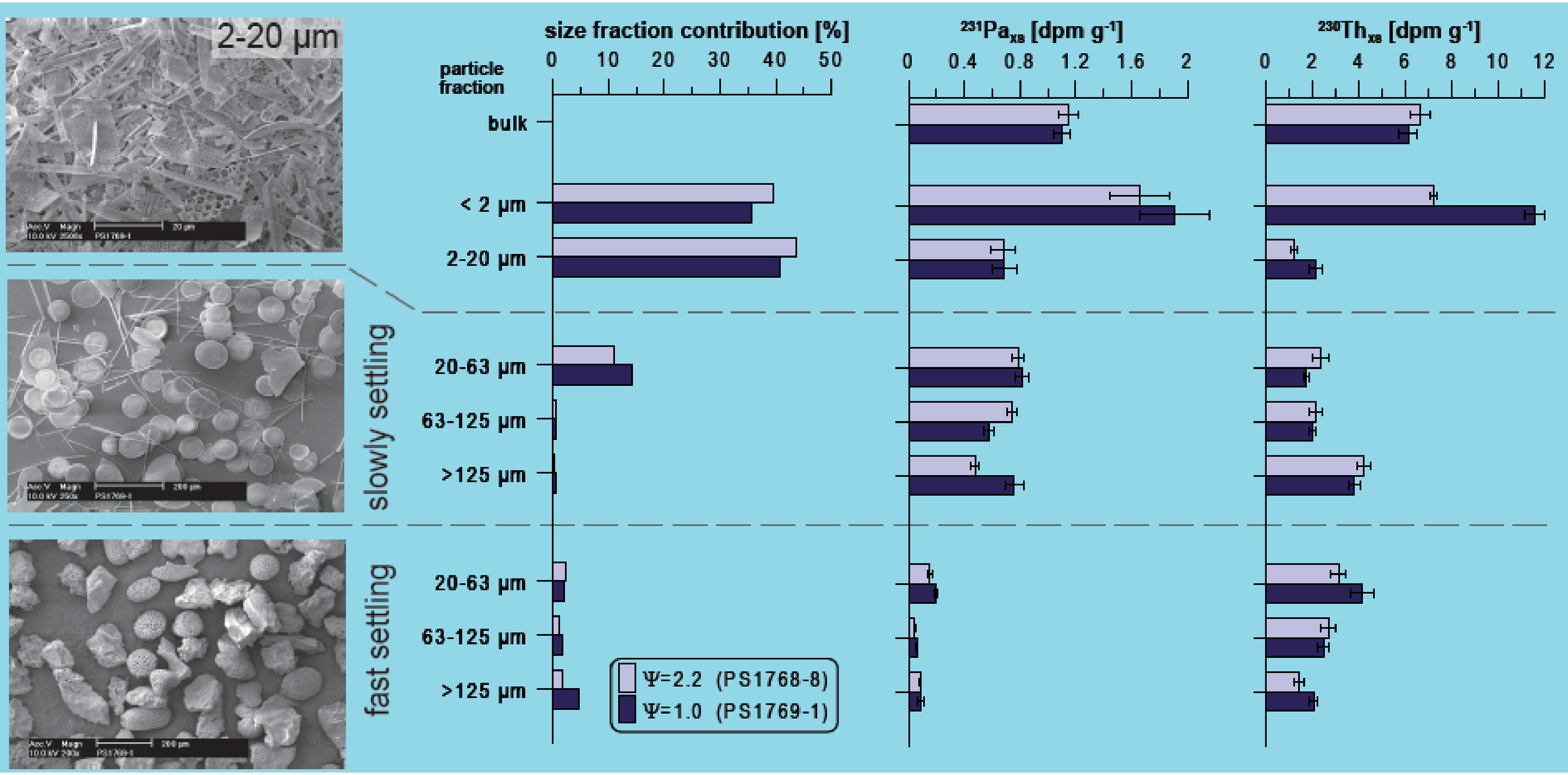




20-63 µm
fast settling

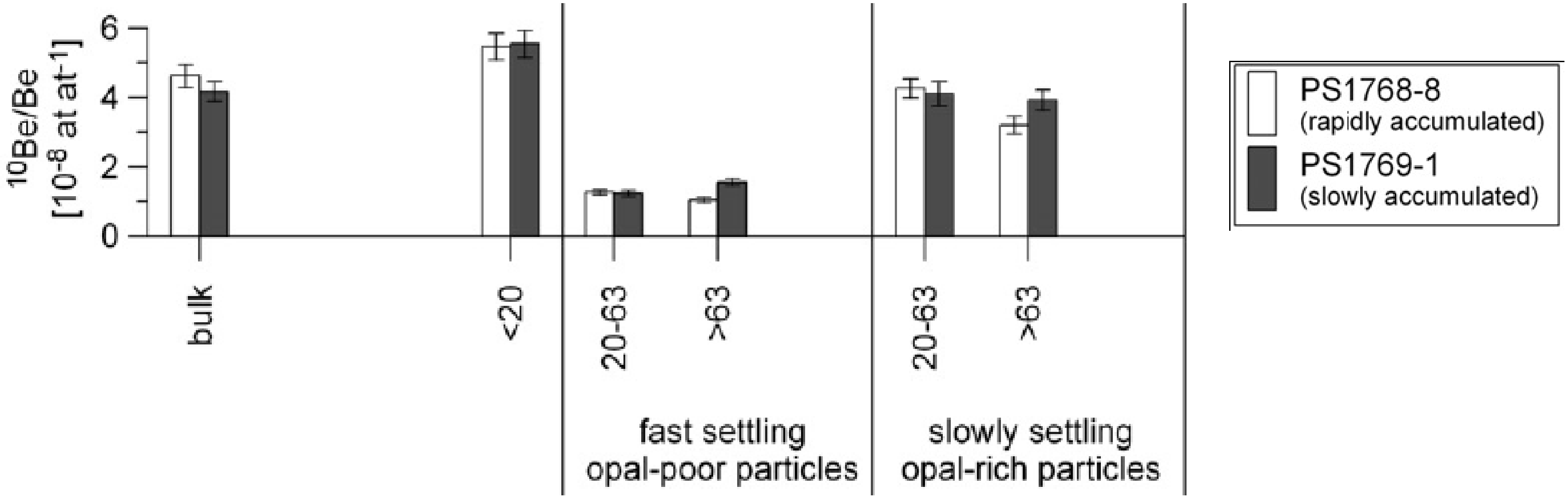
Sven Kretschmer

^{230}Th and ^{231}Pa fractionation by size and sinking rate



Kretschmer et al., 2011

Evidence for remote input of ^{10}Be



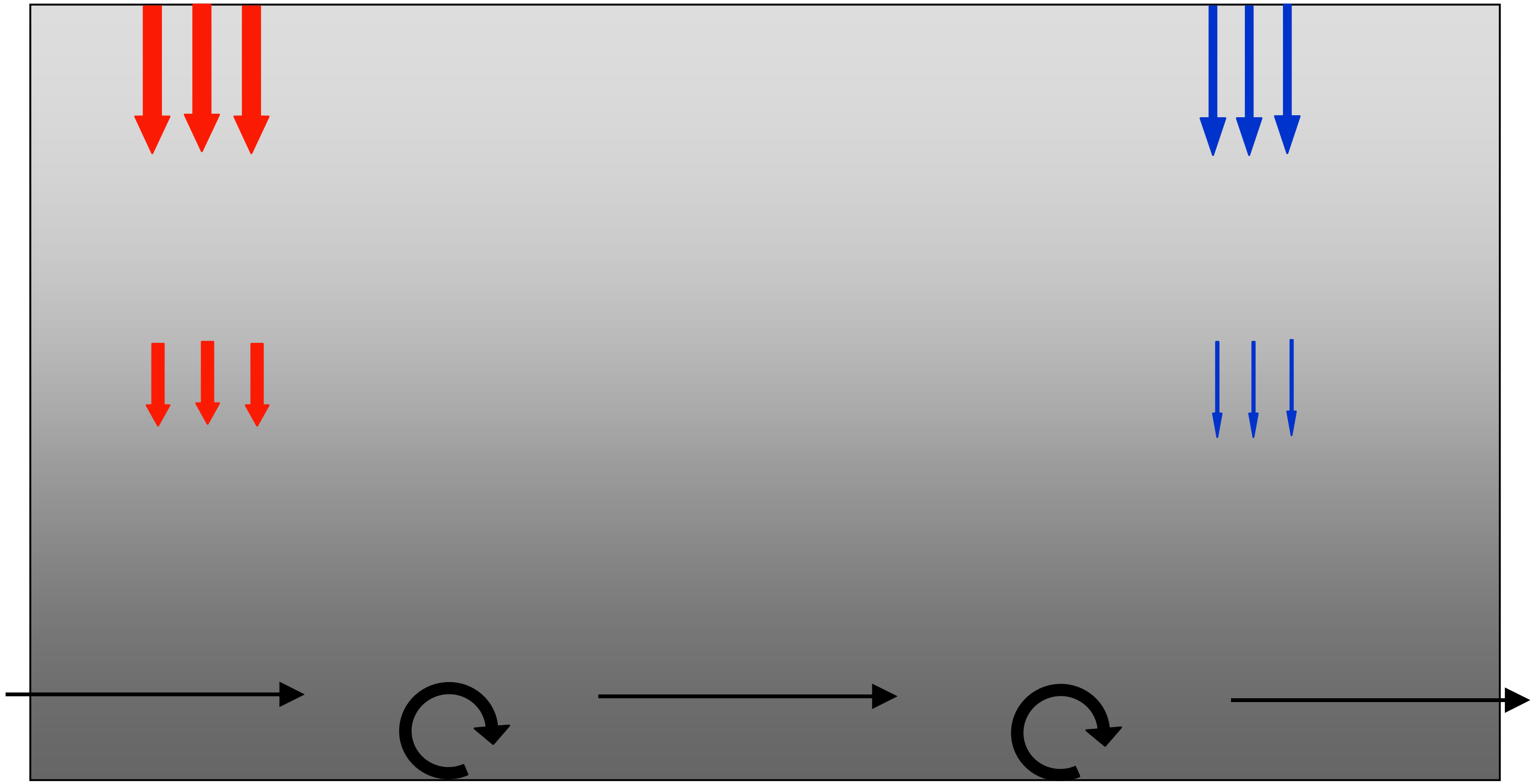
% opal 55-60 55-58 15-17 75-82

Lithogenic part of <20μ fraction enriched in ^{10}Be from deep water

Kretschmer et al., 2011

1- Particles sink through advected water masses and reequilibrate
(sinking particles acquire isotopic signature of deepest approx 1000m)
(^{231}Pa: Thomas et al., 2006)

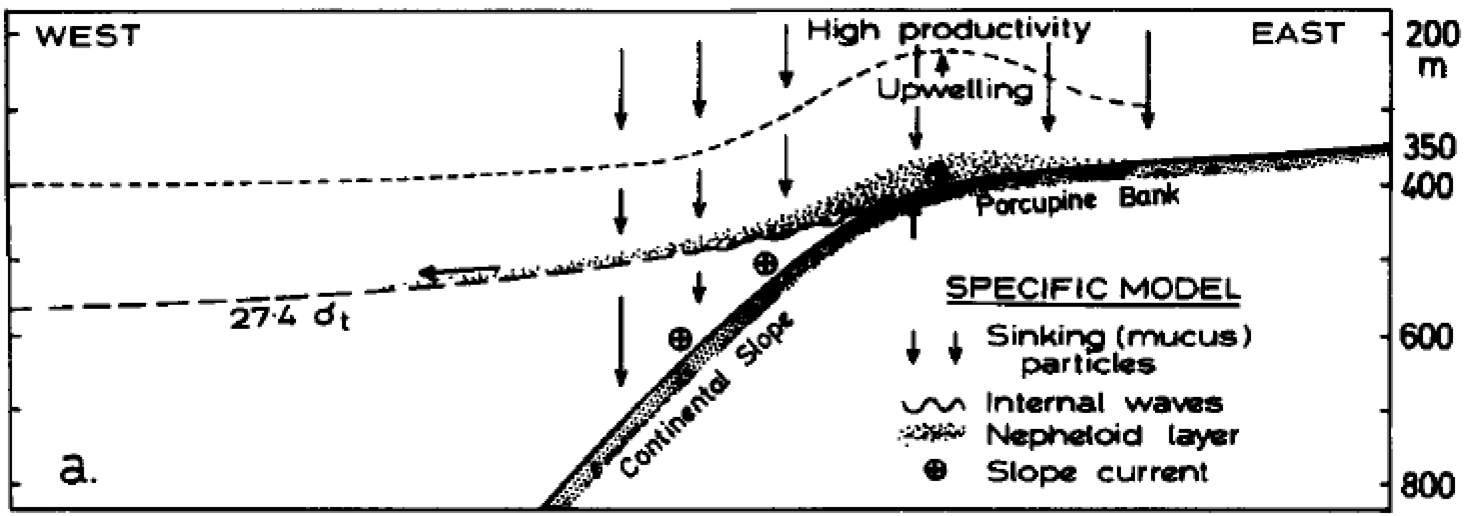
2- a slowly settling fraction of particles (clay, opal) is transported over large distances in the BNL where they mix and exchange with locally produced particles (conflicts with assumptions of ^{230}Th normalization)



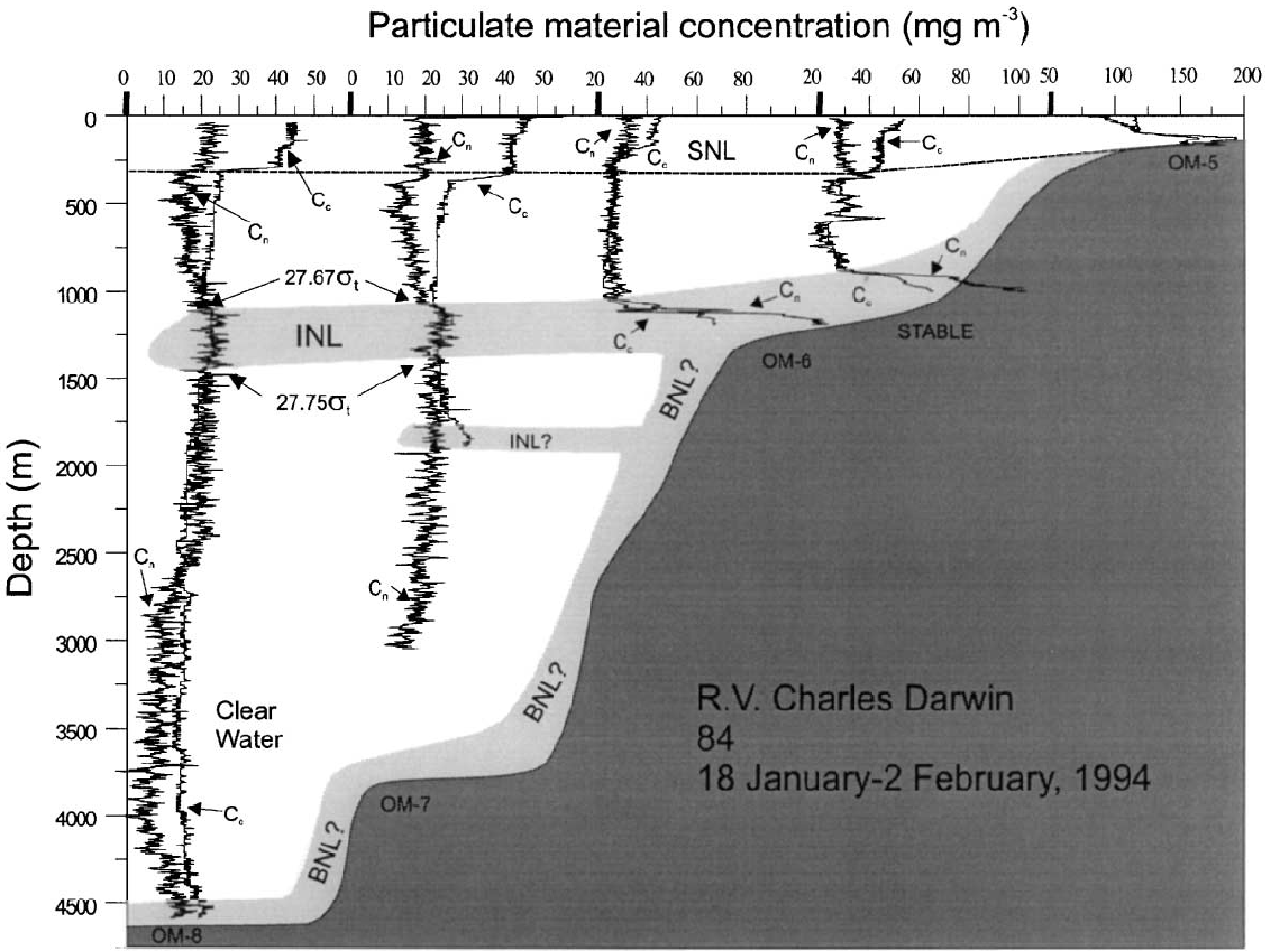
Conclusions on long-range transport in BNL

- Transport among areas with widely different primary sedimentation
- Composition of material suspended in BNL is different from that in clear water above it (cf data Rob Sherrell, Lars Stemmann; what about organic coatings: Peter Santschi?)
- Grain size fractionation. Long range transport of clay minerals
- ^{230}Th, ^{231}Pa and ^{10}Be adsorb preferentially onto the smallest grain sizes
- ^{231}Pa/^{230}Th and ^{10}Be/^{230}Th is enhanced in slowly settling pure opal fraction
- Settling rate fractionation during focussing causes increase in bulk ^{230}Th concentration and in ^{231}Pa/^{230}Th ratio

Intermediate Nepheloid Layers

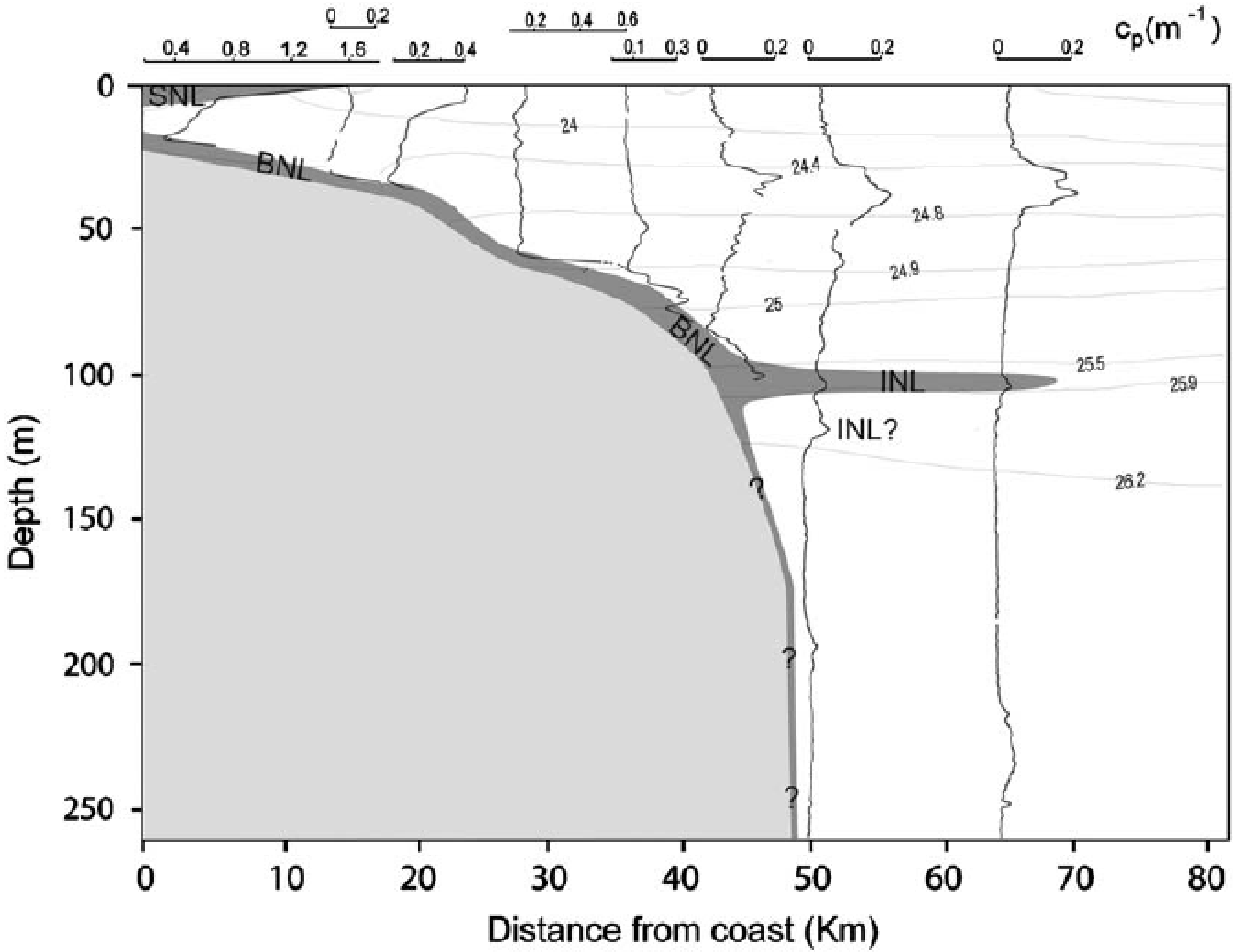


Dickson and McCave, 1986



OMEX: European margin at 47°-50°N

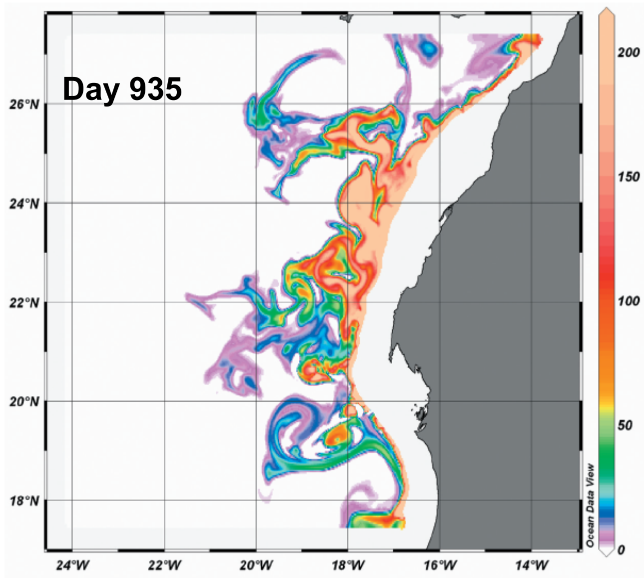
McCave et al., 2001

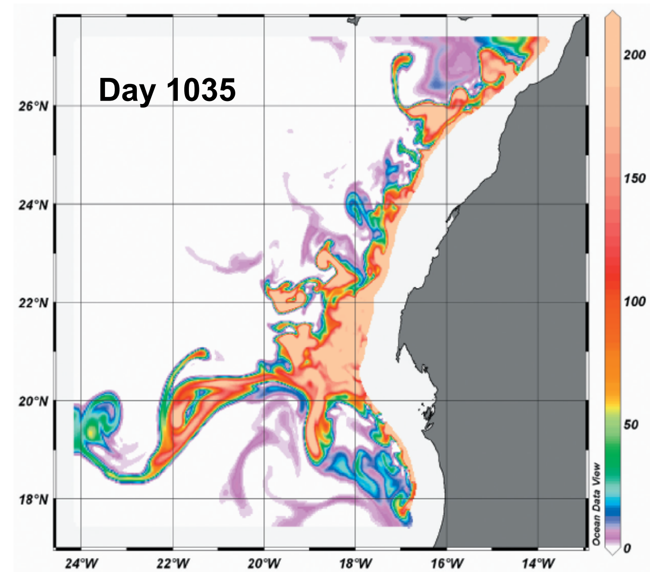


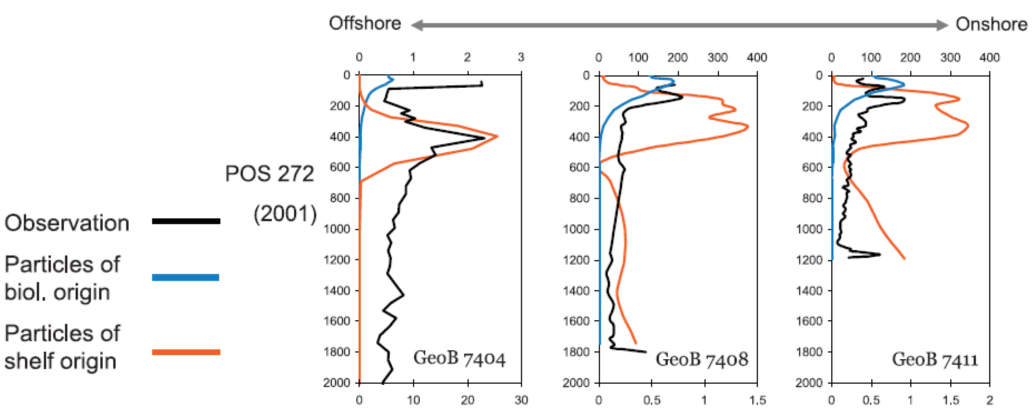
Cariaco Basin, Venezuela

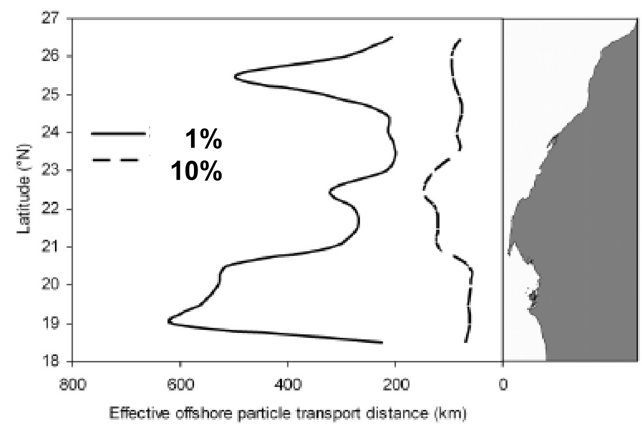
Lorenzoni et al., 2009

Modelled distribution at 500m depth of shelf-derived particles with settling rate of 5 m d-1







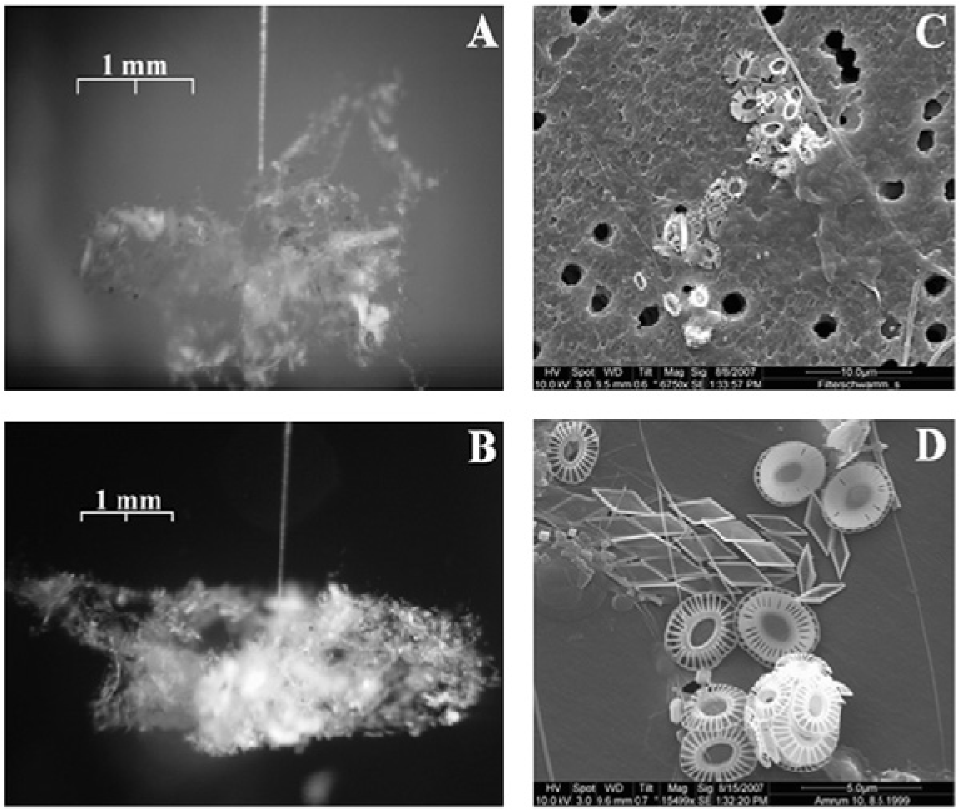


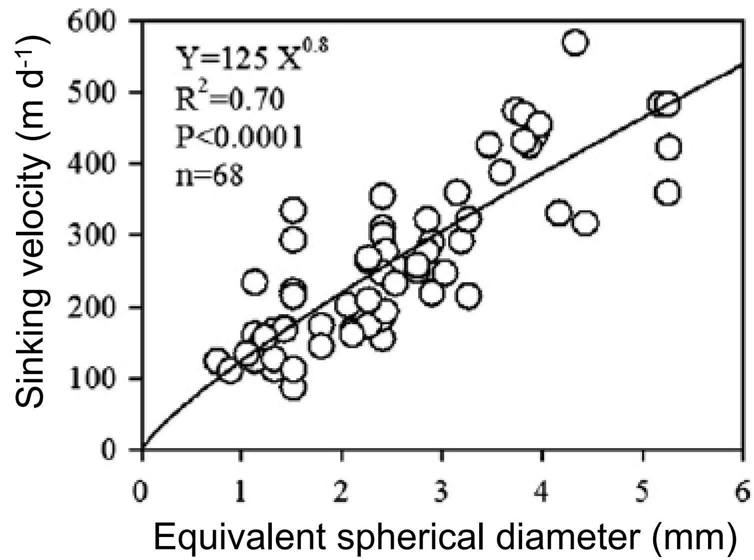
Karakaş et al., 2006

West Africa

Aggregation and sinking rates in INL

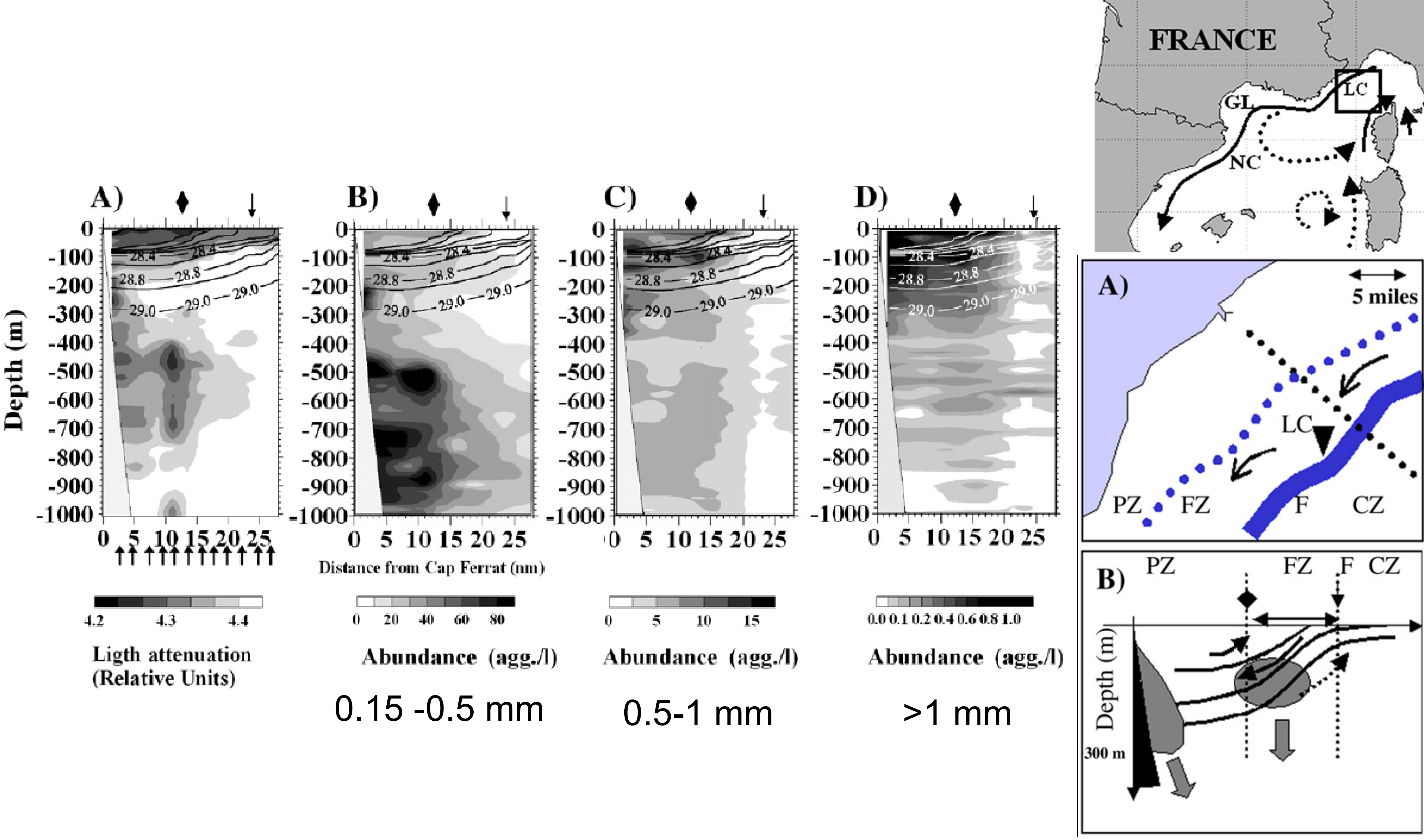
Aggregates formed in roller tanks
In samples from fluorescence max.





cf work of Lionel Guidi, Andy McDonnell, Henne Ploug

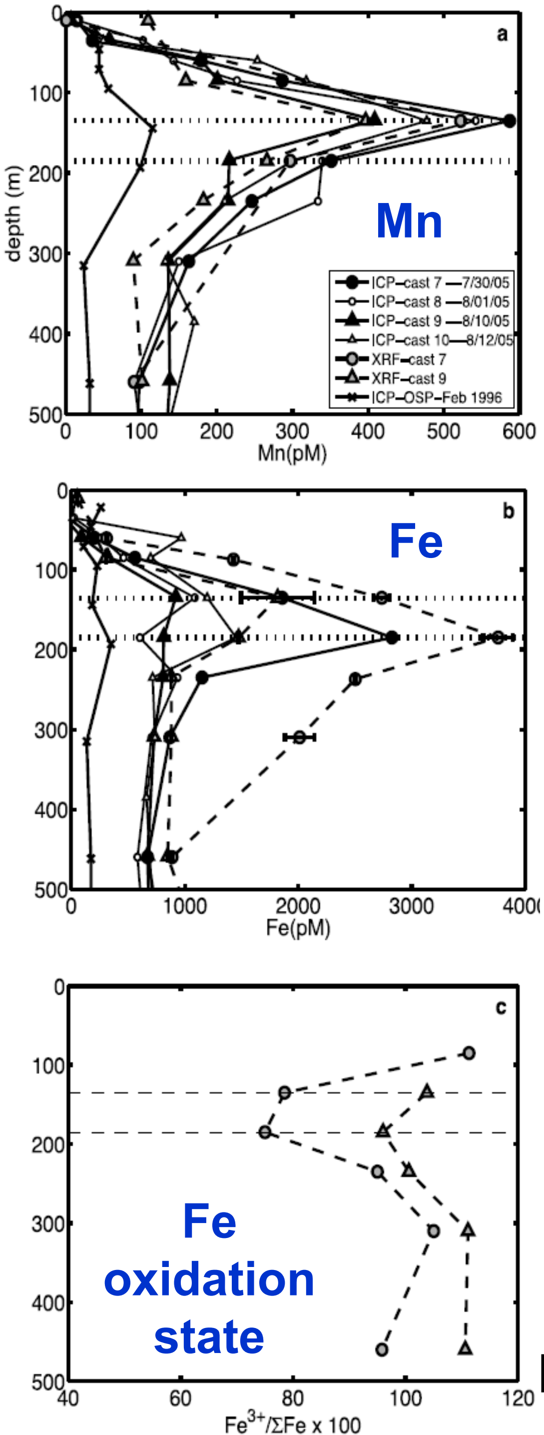
Iversen et al., 2010



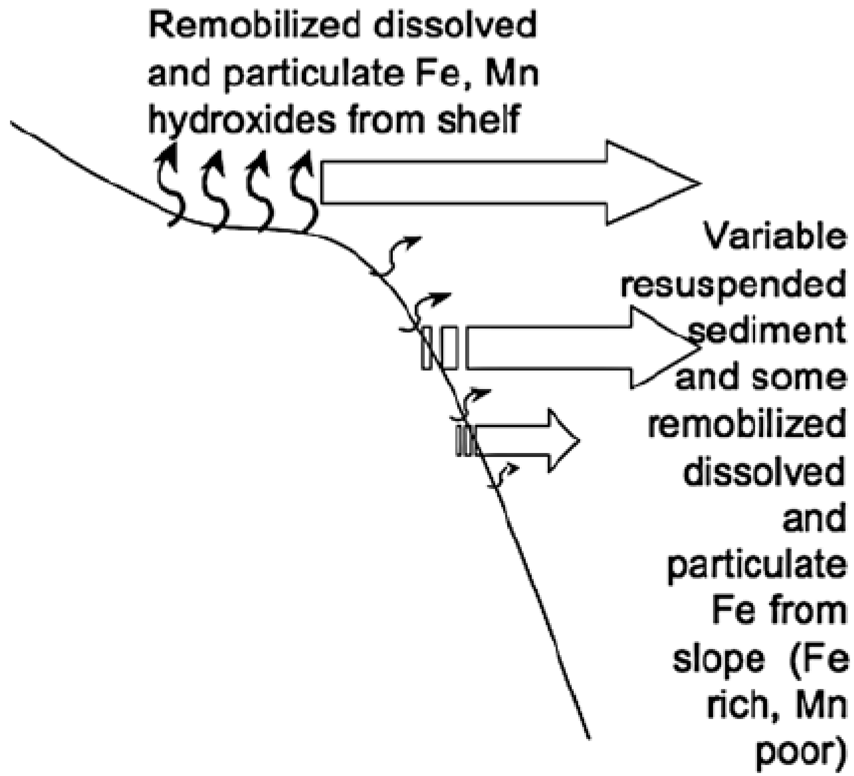
Gulf of Lyon, Mediterranean

Stemman et al., 2008

Particulate (1-51µm) Mn and Fe In NW Pacific



NW Pacific



Lam and Bishop, 2008

Issues on TEIs in INL

- Link between dispersal of particulate (INL) and dissolved tracer signals (e.g. Fe, Mn, ^{210}Pb, Nd)
- Time scale of distribution of shelf inputs (Ra isotopes, ^{228}Th)
- Is the lateral distribution of shelf inputs limited by aggregate formation?

Approach for better representation of processes in nepheloid layers

Measurements:

- Determine adsorption equilibrium in BNL (Pa, Th, Nd, Be)
  - This requires measurement of particle composition and mass concentration
- Determine aggregation and settling rates
- Follow particulate and dissolved signals in INL.

Models:

- Include several particle classes with different adsorption characteristics and settling rates
- Include resuspension/selective deposition to allow for long range transport in BNL

References

- Bacon, M. P. and Rutgers van der Loeff, M. M., 1989. Removal of Thorium-234 by scavenging in the bottom nepheloid layer of the ocean. *Earth Planet. Sci. Lett.* **92**, 157-164.
- Biscaye, P. E. and Eittreim, S. L., 1977. Suspended particulate loads and transport in the nepheloid layer of the abyssal Atlantic Ocean. *Mar. Geol.* **23**, 155-172.
- Boudreau, B. P., 1997. A mathematical model for coupled sediment-suspension interactions. *J. Mar. Syst.* **11**, 279-302.
- Brewer, P. G., Spencer, D. W., Biscaye, P. E., Hanley, A., Sachs, P. L., Smith, C. L., Kadar, S., and Fredericks, J., 1976. The distribution of particulate matter in the Atlantic Ocean. *Earth and Planetary Science Letters* **32**, 393-402.
- Dickson, R. R. and McCave, I. N., 1986. Nepheloid layers on the continental slope west of Porcupine Bank. *Deep Sea Research Part A. Oceanographic Research Papers* **33**, 791-818.
- Diekmann, B., Fütterer, D. K., Grobe, H., Hillenbrand, C.-D., Kuhn, G., Michels, K., Petschik, R., and Pirrung, M., 2004. Terrigenous sediment supply in the polar to temperate South Atlantic: land-ocean links of environmental changes during the late Quaternary. In: Wefer, G., Mulitza, S., and Ratmeyer, V. (Eds.), *The South Atlantic during the Late Quaternary: Reconstruction of Material Budget and Current Systems*. Springer, Berlin, Heidelberg.
- Fu, L.-L., 2009. Pattern and velocity of propagation of the global ocean eddy variability. *Journal of Geophysical Research* **114,**, C11017, doi:10.1029/2009JC005349.
- Hall, I. R., Schmidt, S., McCave, I. N., and Reyss, J. L., 2000. Particulate matter distribution and ^{234}Th/^{238}U disequilibrium along the Northern Iberian Margin: implications for particulate organic carbon export. *Deep Sea Research Part I: Oceanographic Research Papers* **47**, 557.
- Henderson, G. M., Heinze, C., Anderson, R. F., and Winguth, A. M. E., 1999. Global distribution of the ^{230}Th flux to ocean sediments constrained by GCM modelling. *Deep Sea Research Part I: Oceanographic Research Papers* **46**, 1861-1893.
- Hollister, C. D. and McCave, I. N., 1984. Sedimentatino under deep-sea storms. *Nature* **309**, 220-225, doi:10.1038/309220a0.
- Honeyman, B. D., Balistrieri, L. S., and Murray, J. W., 1988. Oceanic trace metal scavenging: the importance of particle concentration. *Deep- Sea Res.* **35**, 227-246.
- Iversen, M. H., Nowald, N., Ploug, H., Jackson, G. A., and Fischer, G., 2010. High resolution profiles of vertical particulate organic matter export off Cape Blanc, Mauritania: Degradation processes and ballasting effects. *Deep Sea Research Part I: Oceanographic Research Papers* **57**, 771-784.
- Karakas, G., Nowald, N., Blaas, M., Marchesiello, P., Frickenhaus, S., and Schlitzer, R., 2006. High-resolution modeling of sediment erosion and particle transport across the northwest African shelf. *Journal of Geophysical Research* **111**, C06025, doi:10.1029/2005JC003296.
- Karakas, G., Nowald, N., Schäfer-Neth, C., Iversen, M., Barkmann, W., Fischer, G., Marchesiello, P., and Schlitzer, R., 2009. Impact of particle aggregation on vertical fluxes of organic matter. *Progress In Oceanography* **83**, 331-341.
- Kretschmer, S., Geibert, W., Rutgers van der Loeff, M. M., and Mollenhauer, G., 2010. Grain size effects on $^{230}Th_{xs}$ inventories in opal-rich and carbonate-rich marine sediments. *Earth and Planetary Science Letters* **294**, 131-142.
- Kretschmer, S., Geibert, W., Rutgers van der Loeff, M. M., Schnabel, C., Xu, S., and Mollenhauer, G., 2011. Fractionation of 230Th, 231Pa, and 10Be induced by particle size and composition within an opal-rich sediment of the Atlantic Southern Ocean. *Geochimica et Cosmochimica Acta* **75**, 6971-6987.
- Lam, P. J. and Bishop, J. K. B., 2008. The continental margin is a key source of iron to the HNLC North Pacific Ocean. *Geophys. Res. Letters* **35**.
- Lorenzoni, L., Thunell, R. C., Benitez-Nelson, C. R., Hollander, D., Martinez, N., Tappa, E., Varela, R. n., Astor, Y., and Muller-Karger, F. E., 2009. The importance of subsurface nepheloid layers in transport and delivery of sediments to the eastern Cariaco Basin, Venezuela. *Deep Sea Research Part I: Oceanographic Research Papers* **56**, 2249-2262.
- McCave, I. N., 1984. Size spectra and aggregation of suspended particles in the deep ocean. . *Deep Sea Res.* **31**, 329-352.
- McCave, I. N., 1986. Local and global aspects of the bottom nepheloid layers in the world ocean. *Neth. J. Sea Res.* **20**, 167- 181.
- McCave, I. N., 2001. Nepheloid layers. In: Steele, J., Thorpe, S., and Turekian, K. (Eds.), *Encyclopedia of Ocean Sciences*. Academic Press, London.
- McCave, I. N. and Hall, I. R., 2006. Size sorting in marine muds: Processes, pitfalls, and prospects for paleoflow-speed proxies. *Geochem. Geophys. Geosyst.* **7**, Q10N05.
- McCave, I. N., Hall, I. R., Antia, A. N., Chou, L., Dehairs, F., Lampitt, R. S., Thomsen, L., van Weering, T. C. E., Wollast, R., and Campbell, W. J., 2001. Distribution,composition and flux of particulate material over the European margin at 47°-50°N. *Deep-Sea Research II* **48**, 3107 –3139.
- Peine, F., Turnewitsch, R., Mohn, C., Reichelt, T., Springer, B., and Kaufmann, M., 2009. The importance of tides for sediment dynamics in the deep sea-Evidence from the particulate-matter tracer (234)Th in deep-sea environments with different tidal forcing. *Deep-Sea Research Part I-Oceanographic Research Papers* **56**, 1182-1202.
- Petschik, R., Kuhn, G., and Gingele, F., 1996. Clay mineral distribution in surface sediments of the South Atlantic: sources, transport, and relation to oceanography. *Mar. Geol.* **130**, 203-229.
- Provost, C., Renault, A., BarrÃ©, N., SennÃ©chael, N., GarÃ§on, V., Sudre, J., and Huhn, O., 2011. Two repeat crossings of Drake Passage in austral summer 2006: Short-term variations and evidence for considerable ventilation of intermediate and deep waters. *Deep Sea Research Part II: Topical Studies in Oceanography* **58**, 2555-2571.
- Renault, A., Provost, C., Sennéchael, N., Barré, N., and Kartavtseff, A., 2011. Two full-depth velocity sections in the Drake Passage in 2006: Transport estimates. *Deep Sea Research Part II: Topical Studies in Oceanography* **58**, 2572-2591.
- Rutgers van der Loeff, M. M. and Boudreau, B. P., 1997. The effect of resuspension on chemical exchanges at the sediment water interface - A modelling and natural radiotracer approach. *J. Mar. Syst.* **11**, 305-342.
- Stemmann, L., Prieur, L., Legendre, L., Taupier-Letage, I., Picheral, M., Guidi, L., and Gorsky, G., 2008. Effects of frontal processes on marine aggregate dynamics and fluxes: An interannual study in a permanent geostrophic front (NW Mediterranean). *Journal of Marine Systems* **70**, 1-20.
- Stommel, H., 1958. the abyssal circulation. *Deep Sea Res.* **5**, 80-82.
- Thomas, A. L., Henderson, G. M., and Robinson, L. F., 2006. Interpretation of the 231Pa/230Th paleocirculation proxy: New water-column measurements from the southwest Indian Ocean. *Earth and Planetary Science Letters* **241**, 493.
- Thomsen, L. and van Weering, T. C. E., 1998. Spatial and temporal variability of particulate matter in the benthic boundary layer at the N.W. European Continental Margin (Goban Spur). *Progr. Oceanogr.* **42**, 61 –76.
- Turnewitsch, R., Reyss, J.-L., Nycander, J., Waniek, J. J., and Lampitt, R. S., 2008. Internal tides and sediment dynamics in the deep sea--Evidence from radioactive 234Th/238U disequilibria. *Deep Sea Research Part I: Oceanographic Research Papers* **55**, 1727.

Parameter values resuspension model

DB	4.3E-08	bioturbation coefficient	m^2d^{-1}	5.0E-08 cm^2s^{-1}
DM	8.6E-06	molecular diffusion coefficient	m^2d^{-1}	1.0E-06 cm^2s^{-1}
E	86.4	eddy diffusion coefficient in BNL	m^2d^{-1}	
h	100	Height of bottom boundary layer (BNL)	m	
k1c	0.001479	adsorption rate constant in clear water	d^{-1}	
k-1	0.008219	desorption rate constant	d^{-1}	
K	0.01	resuspension rate	d^{-1}	
Kd	8.5E+06	distribution coefficient	- (vol/vol)	
L	5.0E-04	Thickness of resuspension zone (surface sediment)	m	
w	-10		cm kyr^{-1}	
ws	-5.8	settling rate	md^{-1}	
alpha	1	reciprocal of characteristic resuspension height	m^{-1}	
phi0	0.9	liquid volume fraction in sediment (porosity)	-	

Bioturbation

Effect on scavenging in BNL