Bottom and Intermediate nepheloid layers

Michiel Rutgers van der Loeff and Sven Kretschmer
Suspended particulate matter during GEOSECS

Longitudinal section of the dry weight of particulate matter in the western Atlantic Ocean.
Hall et al., 2000

Nephelometer = scattering

Transmissometer = beam attenuation

 PMC ($\mu g \, l^{-1}$)

Depth (m)

$\sigma_i$ (kg m$^3$)

Clear Water (~10 $\mu g \, l^{-1}$)

Good Agreement between instruments

Surface nepheloid layer

Attenuation excess

Coarse/organic dominated particles

Shallow intermediate nepheloid layer

Deep intermediate nepheloid layer

Bottom nepheloid layer

Scattering excess

Fines/inorganic dominated particles

Hall et al., 2000
John Toole in GEO Trace 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

Phytodetritus pulses
- Aggregation/Disaggregation
- Faunal activities

Settling and resuspension

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
Resuspension model

Particles tracer

\[ z = h \]

\[ z = 0 \]

\[ z = -L \]

Apply to Halflife Total activity

<table>
<thead>
<tr>
<th>Apply to</th>
<th>Halflife (y)</th>
<th>Total activity BNL/clear water</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{234}\text{Th})</td>
<td>.07</td>
<td>0.86</td>
</tr>
<tr>
<td>(^{228}\text{Th})</td>
<td>1.9</td>
<td>0.26</td>
</tr>
<tr>
<td>(^{210}\text{Pb})</td>
<td>22.3</td>
<td>0.27</td>
</tr>
<tr>
<td>(^{230}\text{Th})</td>
<td>75400</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Bacon and RvdL, 1989; Boudreau, 1997; RvdL and Boudreau, 1997
Particle concentration effect or: is $K_d$ a constant?

Adsorption equilibrium exists when

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

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

$P$ = 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

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

Factor 3.5

10-200 µg/L
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

**dissolved activity**

- **$^{230}$Th**
- **$^{234}$Th**
- **$^{210}$Pb**
- **$^{228}$Th**

**total activity**

- **$^{230}$Th**
- **$^{234}$Th**
- **$^{210}$Pb**
- **$^{228}$Th**
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 (e.g., MnO$_2$ enrichment)
    - Particle dynamics (particle concentration effect, aggregation/disaggregation)
$^{230}$Th section in Pacific

Bottom depletion

Okubo et al., EPSL, submitted
Open University based on Biscaye and Eittreim 1977

Long-range transport in BNL

Suspended Particle Inventory in BNL
(in excess of clear water minimum)
Deep Western Boundary Currents

Stommel, 1958

McCave 1986
Currents through Drake Passage

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

63-125 µm
slowly settling

20-63 µm
slowly settling

> 125µm
fast settling

63-125 µm
fast 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

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
  - $^{230}\text{Th}$, $^{231}\text{Pa}$ and $^{10}\text{Be}$ adsorb preferentially onto the smallest grain sizes
  - $^{231}\text{Pa}/^{230}\text{Th}$ and $^{10}\text{Be}/^{230}\text{Th}$ is enhanced in slowly settling pure opal fraction
- Settling rate fractionation during focussing causes increase in bulk $^{230}\text{Th}$ concentration and in $^{231}\text{Pa}/^{230}\text{Th}$ ratio
Intermediate Nepheloid Layers

Dickson and McCave, 1986
OMEX: European margin at 47°-50°N

R.V. Charles Darwin 84
18 January-2 February, 1994

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$^{-1}$

West Africa

Karakaş et al., 2006
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

Remobilized dissolved and particulate Fe, Mn hydroxides from shelf

Variable resuspended sediment and some remobilized dissolved and particulate Fe from slope (Fe rich, Mn poor)

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

**Parameter values resuspension model**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit(s)</th>
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<tbody>
<tr>
<td>DB</td>
<td>4.3E-08</td>
<td>bioturbation coefficient</td>
</tr>
<tr>
<td>DM</td>
<td>8.6E-06</td>
<td>molecular diffusion coefficient</td>
</tr>
<tr>
<td>E</td>
<td>86.4</td>
<td>eddy diffusion coefficient in BNL</td>
</tr>
<tr>
<td>h</td>
<td>100</td>
<td>Height of bottom boundary layer (BNL)</td>
</tr>
<tr>
<td>k₁c</td>
<td>0.001479</td>
<td>adsorption rate constant in clear water</td>
</tr>
<tr>
<td>k⁻¹</td>
<td>0.008219</td>
<td>desorption rate constant</td>
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<tr>
<td>K</td>
<td>0.01</td>
<td>resuspension rate</td>
</tr>
<tr>
<td>Kd</td>
<td>8.5E+06</td>
<td>distribution coefficient</td>
</tr>
<tr>
<td>L</td>
<td>5.0E-04</td>
<td>Thickness of resuspension zone (surface sediment)</td>
</tr>
<tr>
<td>w</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>ws</td>
<td>-5.8</td>
<td>settling rate</td>
</tr>
<tr>
<td>alpha</td>
<td>1</td>
<td>reciprocal of characteristic resuspension height</td>
</tr>
<tr>
<td>phi₀</td>
<td>0.9</td>
<td>liquid volume fraction in sediment (porosity)</td>
</tr>
</tbody>
</table>
**Bioturbation**

Effect on scavenging in BNL

**dissolved activity**

- $^{230}$Th
- $^{234}$Th
- $^{210}$Pb
- $^{228}$Th

**total activity**

- $^{230}$Th
- $^{234}$Th
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