12.742 - Marine Chemistry Fall 2004

Lecture 15 - Sinking Particles + Remineralization

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Twilight zone 100-1000m Rapid drop off of POC and PON with depth

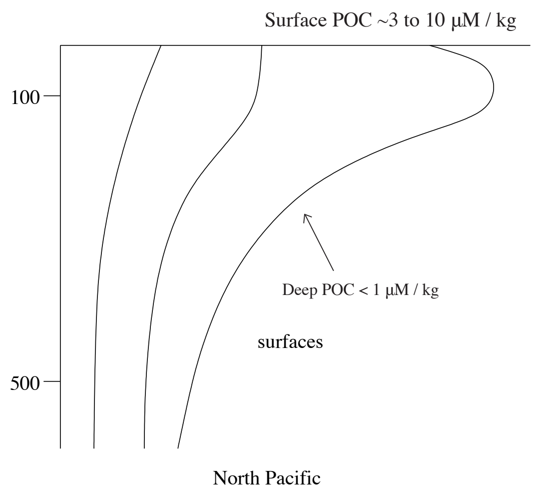

Figure 1.

- Active bacteria and zooplankton communities
- Bacterial; see rise in Arches at depth
- Zooplankton vertical migrations
- nycthemeral (daily) or onthogenic (seasonal)
- daily migrate up at night (feeding) - (net downward vertical flux)

- Separation of organic material int oPOC vs. DOC; Operational depending on filter size (0.4μm); 30-50% may be colloidal.
- 0.45μm Glass fiber filter GF/F
- colloidal $\sim$ 10,000 daltons $\rightarrow$ diameter of 0.4μm
- POM filtering and then elemental analyzer, beam attenuation transmisometer
- DOM more difficult - because of salt and recalcitrant DOM
- As move down water column, can identify less and less of DOM as specific compounds
- UV-oxidation, high temperature oxidation
- DOM "suspended"; POM "sinks"
- DOM pool, large $\sim$ 700 Pg C
- POM pool drops off sharply with depth
- Only a few Pg C
- POM sinking / Particulate matter (POM, $CaCO_3$, SiO_2, dust)
- biological production, aeolian deposition, riverine inputs, shelf/slope resuspension

- $3 - 10\mu$m/kg in upper 100 meters - drop off sharply with depth

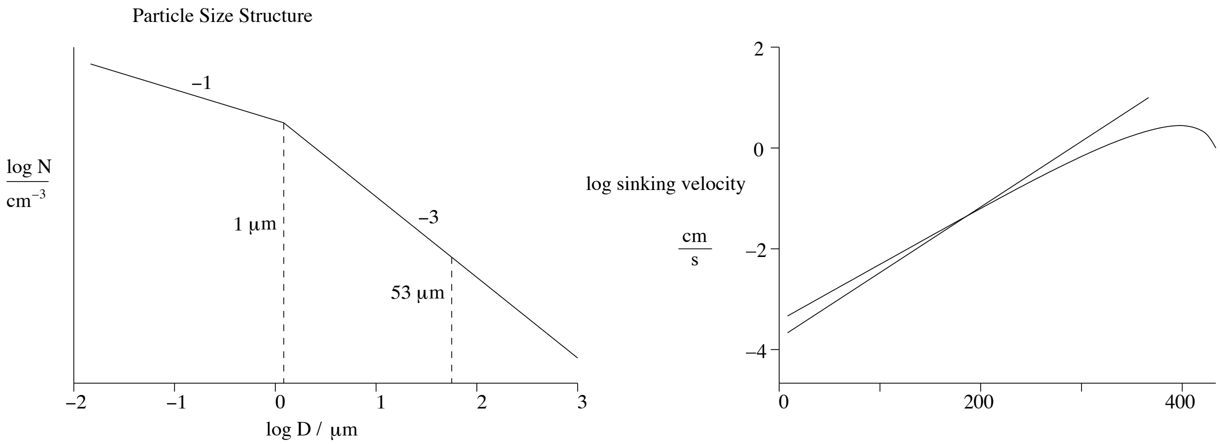

Figure 2.

- Particle size spectrum - mechanisms exchanging particles between size clusters

Stokes' Law for small particles-gravitational force balanced by molecular viscous drag. For spherical particles:

$$w_{sink} = 2gr^2 \frac{\rho_{part} - \rho_{sw}}{9\mu} \tag{1}$$

Where:

$$\begin{aligned} r^2 &= \text{radius [m]} \\ \rho &= \text{density [kg m}^{-3}\text{]} \\ \mu &= \text{viscosity dynamic} \left[\frac{\text{N s}}{\text{m}^2}\right] \end{aligned}$$

McCave (1975)

Stokes Law for large particles ($> 100\mu m$)–gravitational force balanced by turbulent wake drag. For spherical particles:

$$w_{sink} = \left(\frac{16rg(\rho_{part} - \rho_{sw})}{3\rho_{sw}}\right)^{\frac{1}{2}} \tag{2}$$

- Verticle sinking flux driven by large, rare particles
- ballast materials important

Rough Scaling

$$\begin{aligned}
\rho_{sw} &\sim 1027 \text{ kg/m}^3 \\
\rho_{org} &\sim 1060 \text{ kg/m}^3 \\
\rho_{\mathrm{CaCO_3}} &\sim 2700 \text{ kg/m}^3 \\
\rho_{lithographic} &\sim 2700 \text{ kg/m}^3 \\
\rho_{opal} &\sim 2100 \text{ kg/m}^3 \\
\mu &\sim 1.25 \times 10^{-3} \text{ N} \cdot \text{s} \cdot \text{m}^{-2}
\end{aligned}$$

so

- 50μm organic particles $\rightarrow$ 12 m/day, $\sim$ 1 year for 4000 meters
- $CaCO_3$ $\rightarrow$ 400 m/day, $\sim$ 1 week for 4000 meters

- surface area r^2
- volume r^3

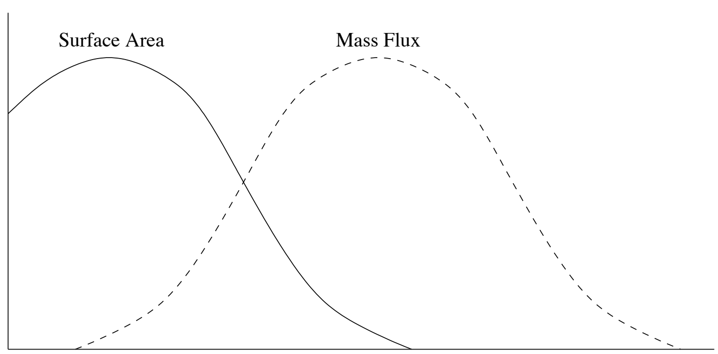

Figure 3.

Vertical Mass Flux

Deep moored sediment traps

- All the issues of traps
- Hydrodynamics - less turbulant at depth (sometimes)
- Swimmers - reduced biomass
- Attach current meters to traps
- Rotating cups (time-series) 6-12 month deployment
- 500 m, 1500 m, 2500 m, 4000 m
- Mass flux - org, $CaCO_3$, Silica, lithogenic
- Particle Velocities; lagged peak correlations

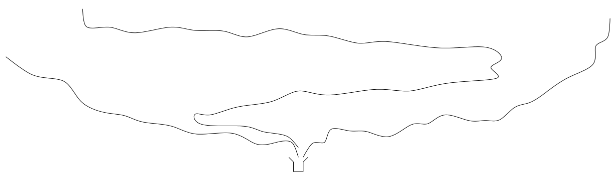

Figure 4.

- Wide statistical cone - sinking particles "sink" at very oblique angles
- Say 100 m/day; horizontal currents of mesoscale eddies O(10 cm/s)

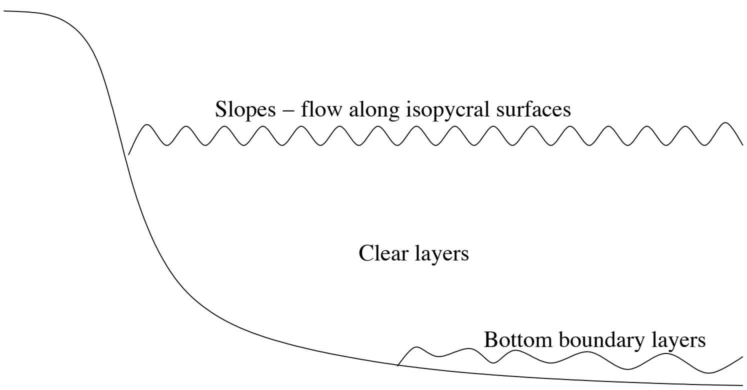

Figure 5.

- nepheloid layers, turbulent resuspension
- High eddy/kinetic energy (storms, DWBC)

Rapid loss of organic matter with depth

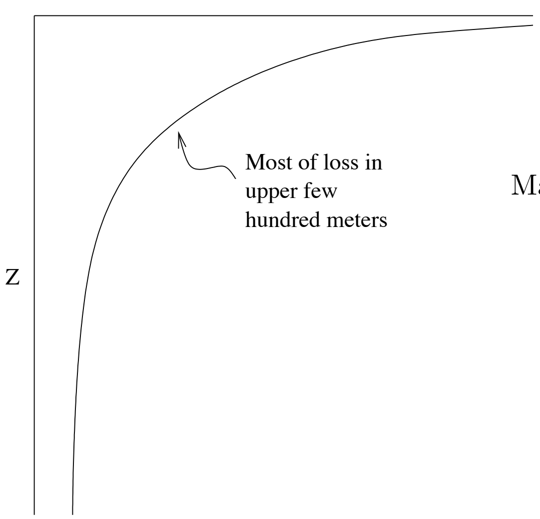

Figure 6.

Martin et al. (1987) synthesis of VERTEX data

$$\begin{aligned} \text{Flux}(z) &= \text{Flux}(z_0)\left(\frac{z}{z_0}\right)^{-b} \\ z_0 &= 100\text{m} \\ b &= 0.858 \qquad \text{(Berelson, 2001)} \;\; 0.82 \pm 0.16 \end{aligned}$$

- mechanism: large sinking $\rightleftarrows$ small suspended (repackaging)
- Zooplankton consumption (filter feeders) or processing into small particles

- Attached bacteria - extracellular enzymes - thought small
- Mechanical/turbulent disruption
- Bacterial respiration (thymidine incorporation, ETS), grazing rates, ree respiration rates large
- Mass imbalance
- Rapid fall off with depth, artifact → fluxes because simple sampling of biomass (Michaels and Silver)
- Hydrothermal particles/plumes
- Iron sulfides, manganese oxides, MnO_2 "downstream" of ridges.
- Ballast - organic matter synergy
- Organic matter makes small inorganic particles bind together to create larger aggregate with larger sinking speed - e.g. how do small $CaCO_3$ liths reach the sea floor
- ballast added to ↑ sinking speed (Armstrong et al. 2002)
- deep water sinking particles tend to approach ∼ constant POC/ballast

Two Exponential Model

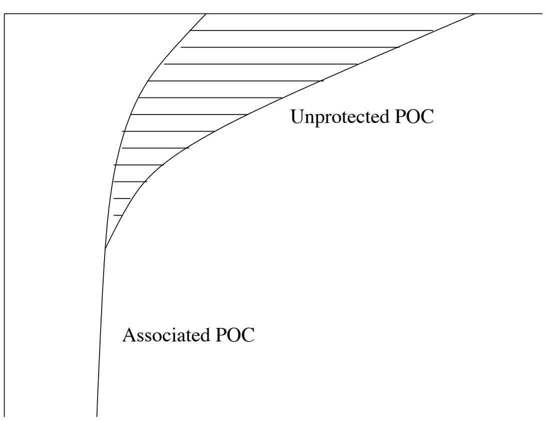

Figure 7.

- Associated but not protected/bound
- Silica near surface
- $CaCO_3$ at depth density, distribution of $CaCO_3$ prod. transfer efficiency

- Marine snow, aggregates

  Biological structures, mucus, feeding structures (appendicularians)

  Biological aggregation, spontaneous formation DOM → colloids, microaggregation

  Diatom flocculation

Constraining particle interactions - U-Th isotopes
a simple model of particle interactions

- Two size classes sinking/suspended
- biological mediation

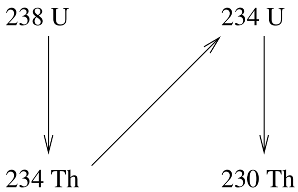

Figure 8.

- ^{234}U preferentially released from rocks during weathering because of α recoil
- Th is very particle reactive

$$k_{scav} = \lambda_{230} \cdot \frac{A_{U_{234}} - A_{Th_{230}}}{A_{Th_{230}}} \tag{3}$$

$$\tau_{scav} = \frac{1}{\lambda_{230}} \cdot \frac{A_{Th_{230}}}{A_{U_{234}} - A_{Th_{230}}} \tag{4}$$

$$= \frac{1}{9.22 \times 10^{-6}} \cdot \frac{10^{-3}}{2.7 - 10^{-3}} \approx 40 \text{ years} \tag{5}$$

Irreversible Scavenging

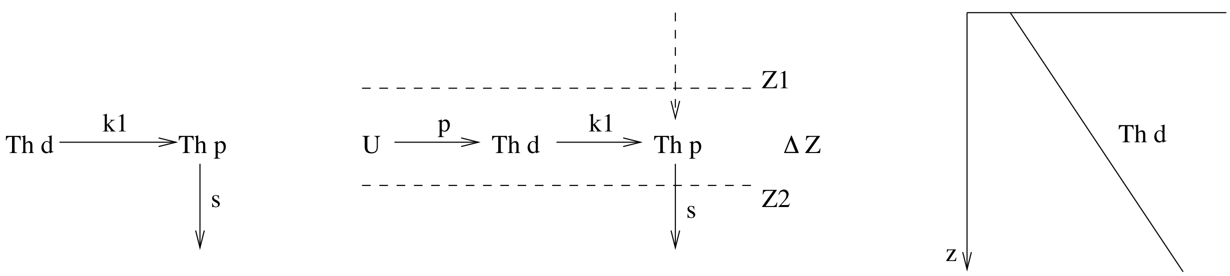

Figure 9.

At steady state:

$$\begin{aligned} A_{U_{234}} &= k_1 Th_d + \lambda Th_d \\ k_1 Th_d &= \lambda Th_p + \frac{[sTh_p(z_2) - sTh_p(z_1)]}{\Delta z} \\ &= \lambda Th_p + s\left(\frac{\partial Th_p}{\partial z}\right) \end{aligned}$$

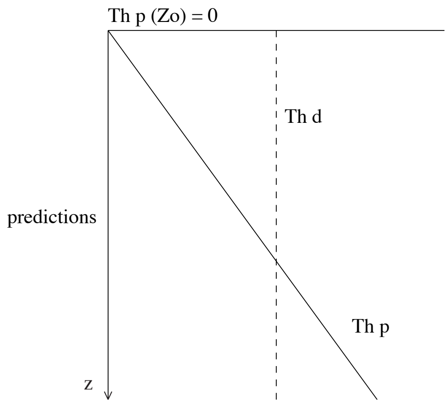

Figure 10.

for ^{230}Th, $k_1 \gg \lambda$

$$Thd = \frac{A_{U_{234}}}{k_1 + \lambda} \quad \approx \quad \frac{A_{U_{234}}}{k_1}$$

Plug back into Th_p:

$$A_{U_{234}} \approx \lambda Th_p + s\left(\frac{\partial Th_p}{\partial z}\right)$$

Assume $A_{U_{234}} \gg A_{Th_{230,p}}$:

$$\begin{aligned} A_{U_{234}} &\approx s\left(\frac{\partial Th_p}{\partial z}\right) \\ &\Longrightarrow Th_p = \frac{A_{U_{234}}}{s} \cdot z \end{aligned} \tag{6}$$

What you often measure is $s \cdot Th_p$, or flux

Reversible Scavenging

$$\begin{aligned} A_{U_{234}} + K_{-1}Th_p &= k_1 Th_d + \lambda Th_d \\ Th_d &= \frac{(A_{U_{234}} + k_{-1}Th_p)}{(k_1 + \lambda)} \\ k_1 Th_d &= (\lambda + k_{-1})Th_p + s\left(\frac{\partial Th_p}{\partial z}\right) \\ Th_p &= \frac{k_1 A_{U_{234}}}{[k_{-1} + k_1 + \lambda]\lambda}\left(1 - \exp\left(\frac{\lambda(k_{-1} + k_1 + \lambda)}{s(k_1 + \lambda)} z\right)\right) \end{aligned} \tag{7}$$

k_1 and $k_{-1} \gg \lambda$

$$Th_d \approx \frac{(A_{U_{234}} + k_{-1}Th_p)}{k_1} \tag{8}$$

give slope to $^{230}Th_d$

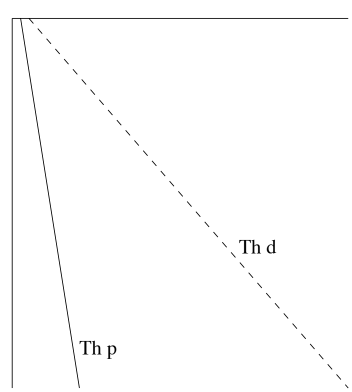

Figure 11.

$$
\begin{aligned}
s\left(\frac{\partial Th_p}{\partial z}\right) &= A_{U_{234}} \\
\Longrightarrow Th_p &= \frac{A_{U_{234}}}{s} z \qquad (9)
\end{aligned}
$$

About 20% of Th is adsorbed onto particles.

$$\tau_{particles} = \frac{\tau_{Th}}{1} \frac{Th_p}{Th_p + Th_d}$$

From this, find

$$\tau_{Th} \approx 40 \text{ years} \qquad (10)$$

$$\tau_{particles} \approx 8 \text{ years} \qquad (11)$$

- For 4,000 m $\Longrightarrow$ $s \sim 500$ m/yr
- Metals "see" small, mostly suspended particles
- Traps "see" large, rapidly sinking particles

One More Level of Sophistication

Size classes, particle formation/creation, adsorption/desorption

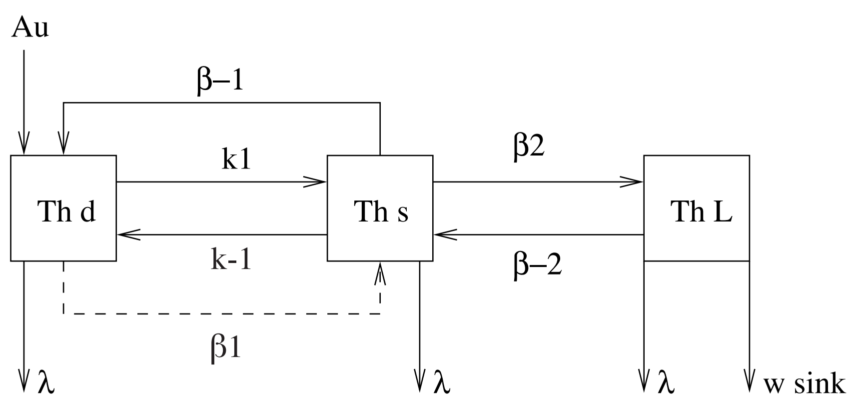

Figure 12.

- Sediment Trap Calibration

$$\text{Flux} = s \cdot Th_p \approx A_{U_{234}} \cdot z \qquad \text{look for excess/deficit}$$

- ^{230}Th versus ^{231}Pa, Th is more particle reactive
  ^{231}Pa comes from ^{235}U and has $\tau_{1/2}$ of 32,000 years
  *Constant Production ratio = 0.093

To find production (in terms of activities) NOT reach secular eq.

$$\begin{aligned}\lambda_{Th} A_{U_{234}} &= 2.5 \times 10^{-5} \text{dpm/l}/yr \\ \lambda_{Pa} A_{U_{234}} &= 2.3 \times 10^{-6} \text{dpm/l}/yr\end{aligned}$$

$Th \sim 40$	year scavenging	−trapping efficiency Bacon et al. 1985
$Pa \sim 100 - 200$	year scavenging	−boundary scavenging

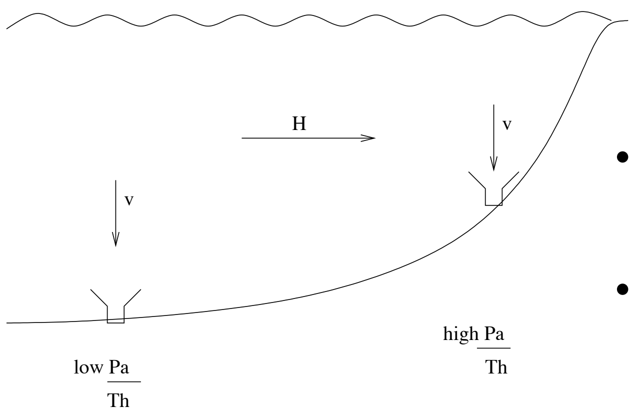

Figure 13.

- With two isotopes can separate effects of vertical transport vs. lateral
- Deep trapping efficiency below 1500 m : 98% ± 14%