The Fate of Particulate Organic Material in the Oceans

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University of Georgia, Athens, Georgia, USA

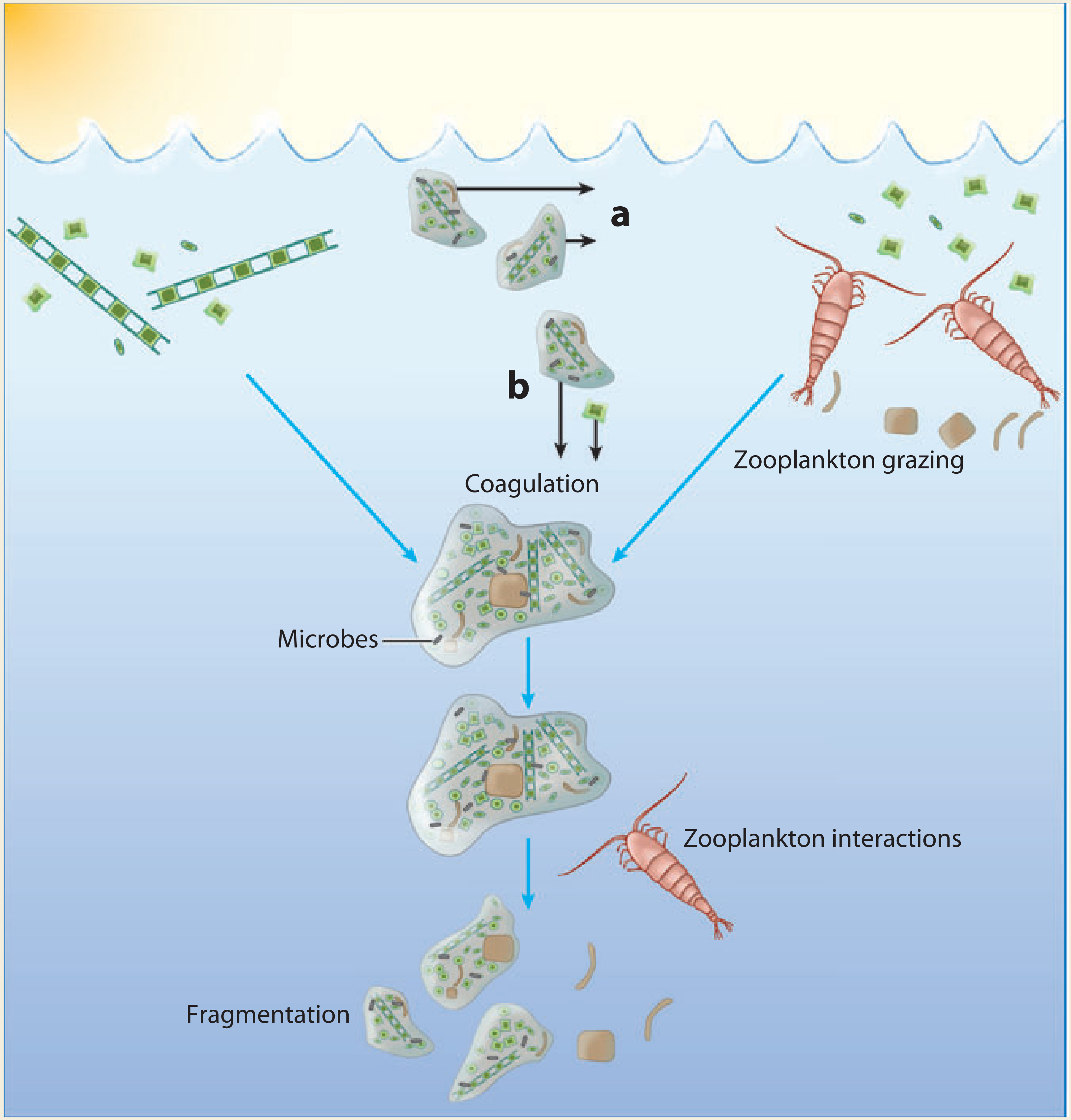
Outline

- **Why is remineralization in the oceans important?**
- **Processes affecting remineralization**
    - *Particle type & properties, concentration, settling speed, **biology***
- **Representing remineralization in models**

Why?

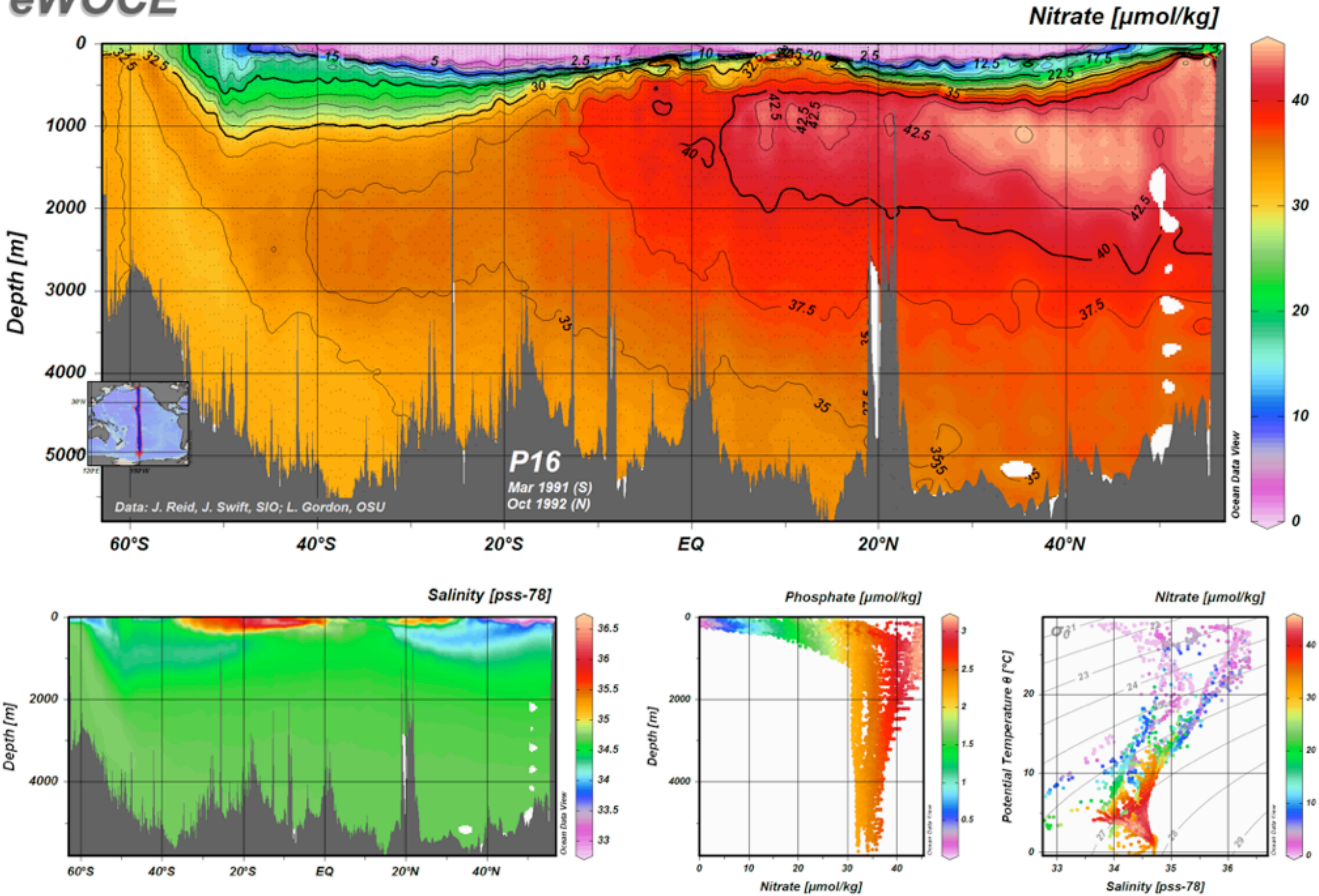
- **Flux**
  - *Crucial role in biogeochemical cycles in the ocean.*
- **Climate**
  - *Sinking particles can sequester carbon in the deep*
- **Trace Metals**
  - *Particles provide surfaces for trace-metal sorption*
- **Deep Water Ecology**
  - *Sinking particles provide food for deep water organisms*

Processes affecting particles



Burd & Jackson, *Ann. Rev. Mar. Sci.*, 1:65–90, 2009

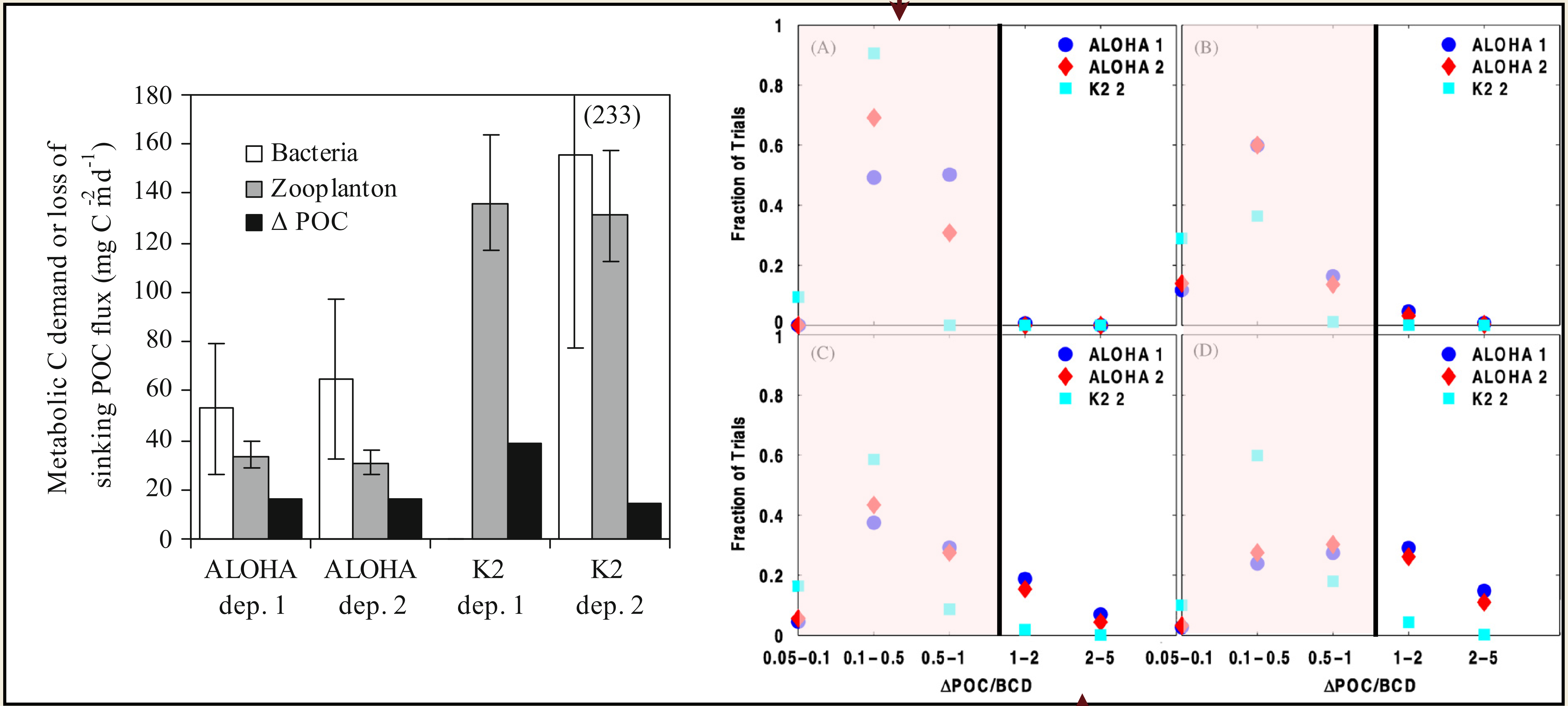
eWOCE



Nitrate [µmol/kg]
Depth [m]
P16
Mar 1991 (S)
Oct 1992 (N)
Data: J. Reid, J. Swift, SIO; L. Gordon, OSU
60°S
40°S
20°S
EQ
20°N
40°N
Ocean Data View
Salinity [pss-78]
Phosphate [µmol/kg]
Nitrate [µmol/kg]
Potential Temperature θ [°C]
Salinity [pss-78]

Feeding the Deep Ocean?

Insufficient Carbon

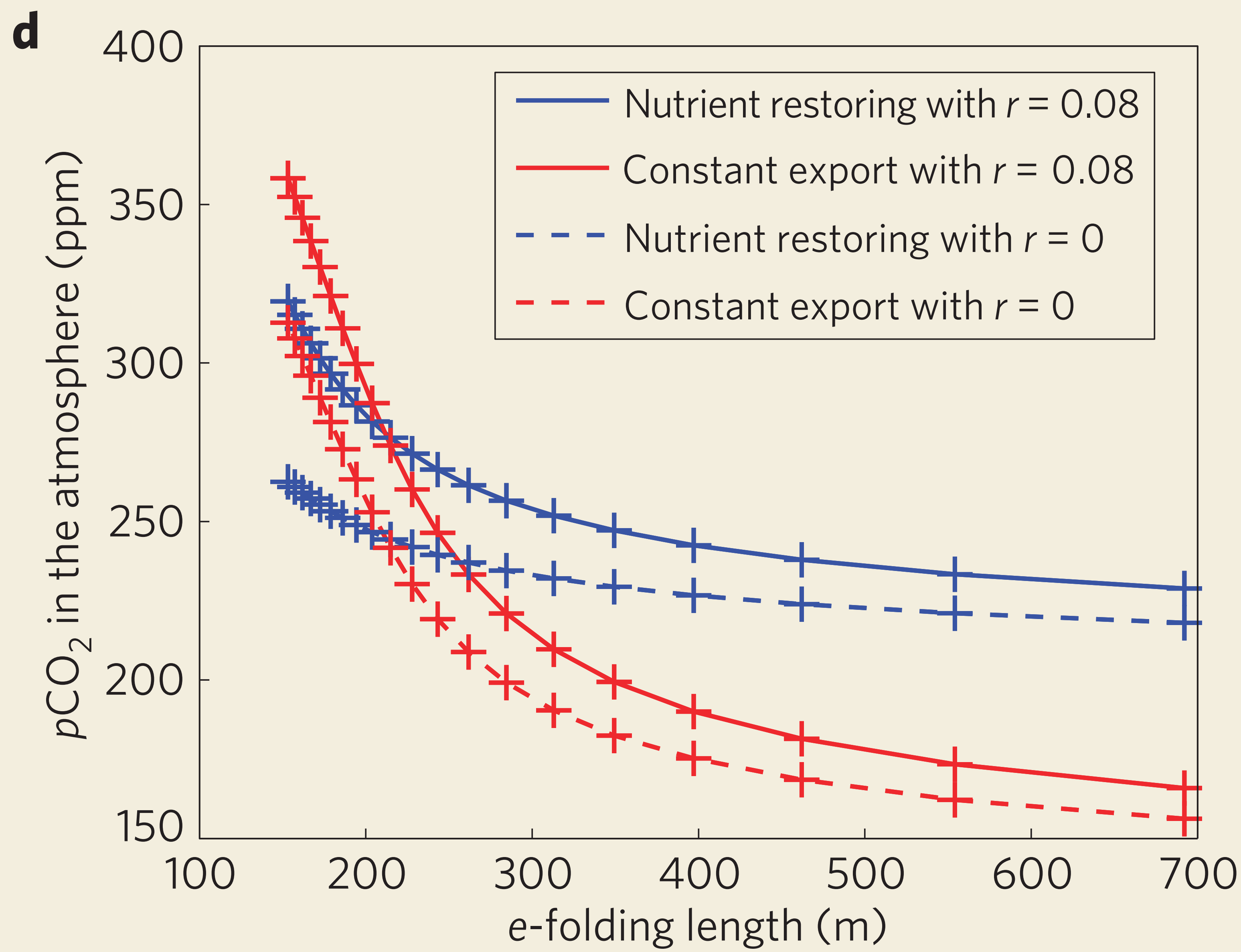


Steinberg et al., *Limnol. Oceanogr.* 2008

Burd et al., *Deep-Sea Res. II,* 2010

Sufficient Carbon

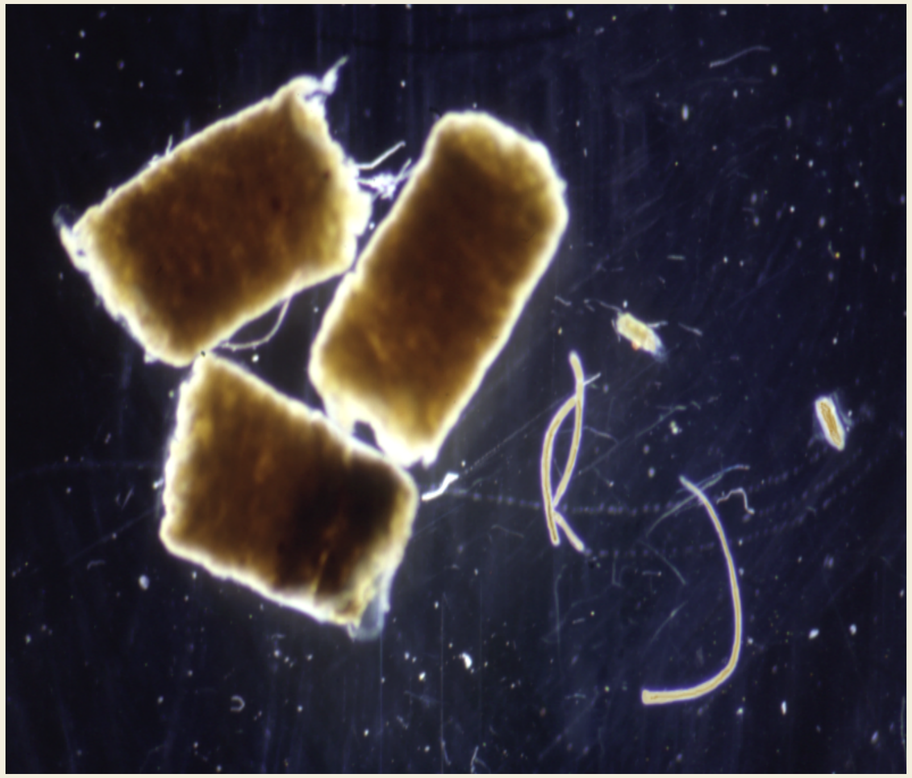
Carbon sequestration



Kwon et al., *Nature Geosci.,* 2:630–635, 2009

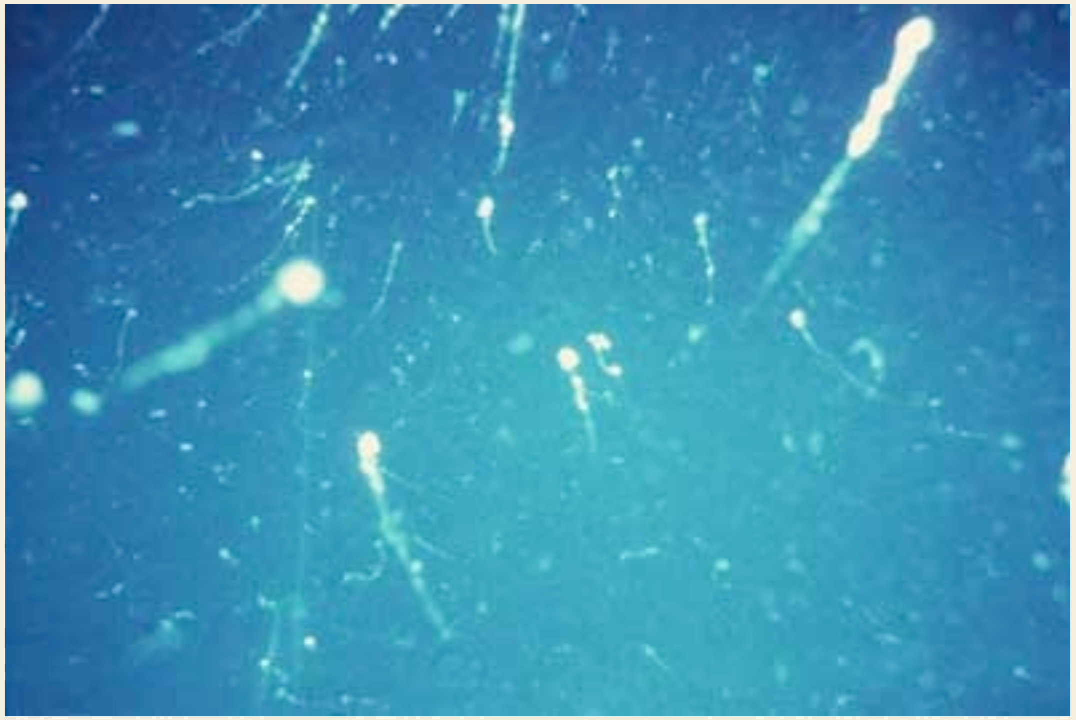
What are marine particles?

Alice Alldredge



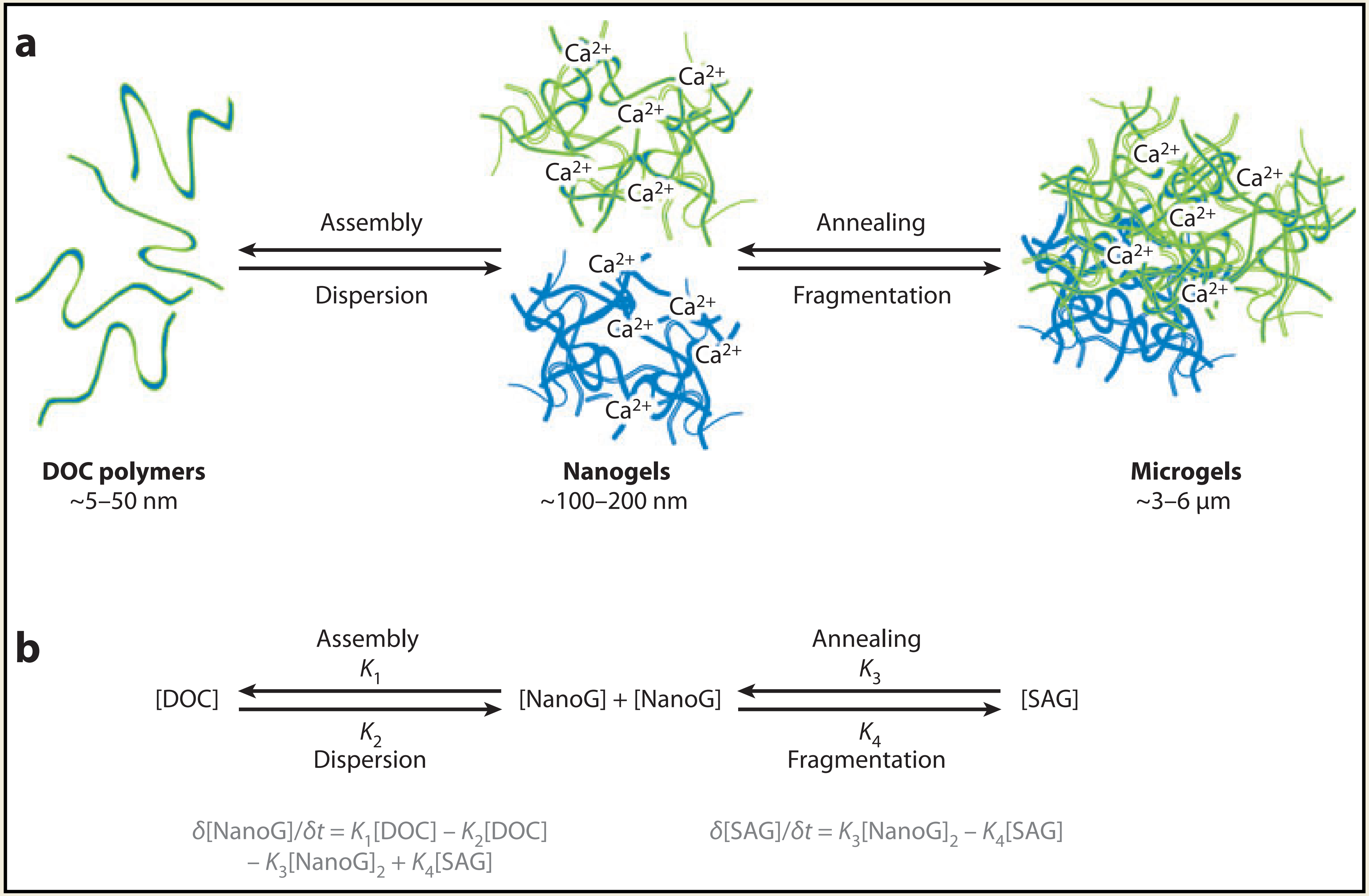
Debbie Steinberg

Richard Lampitt



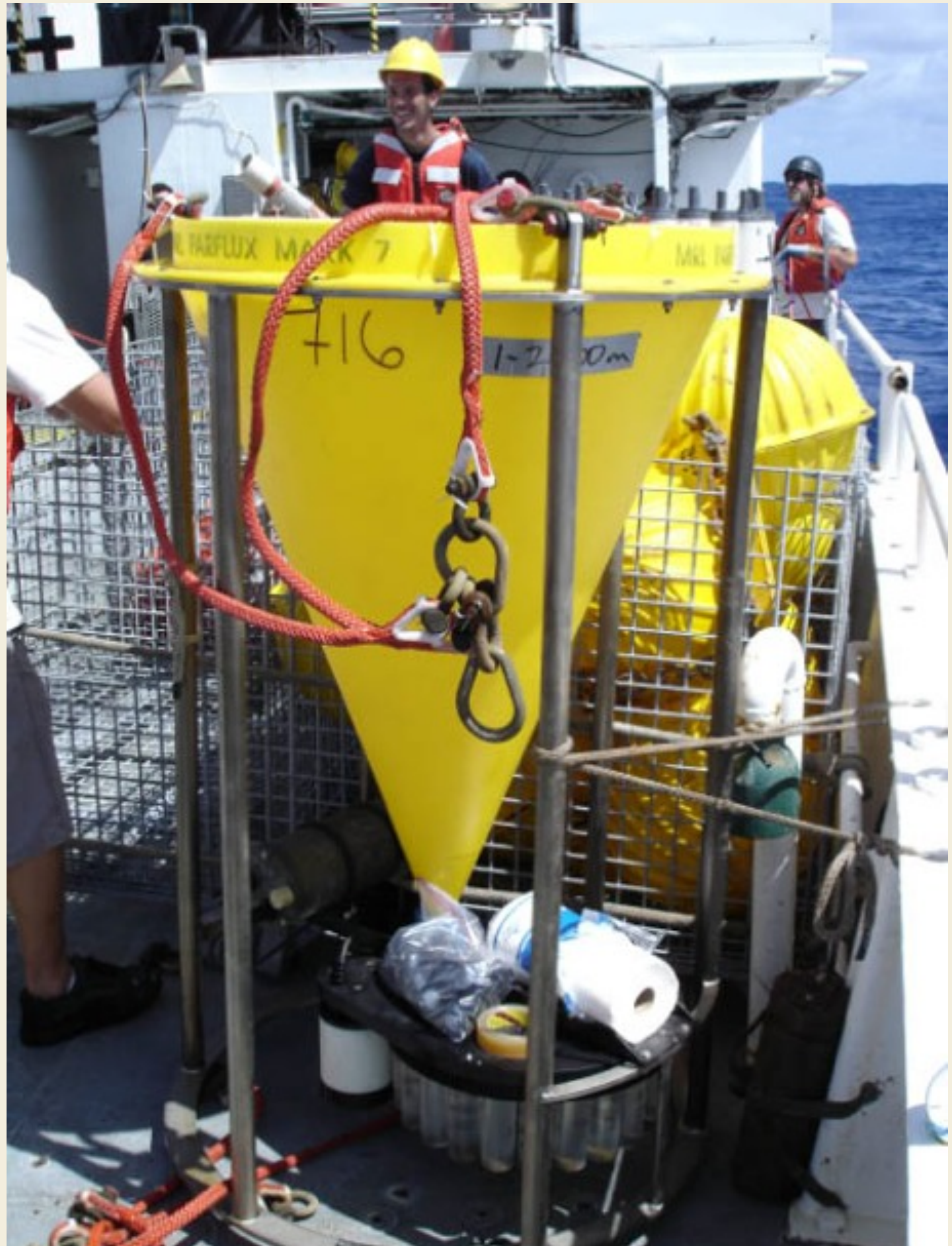
Alice Alldredge

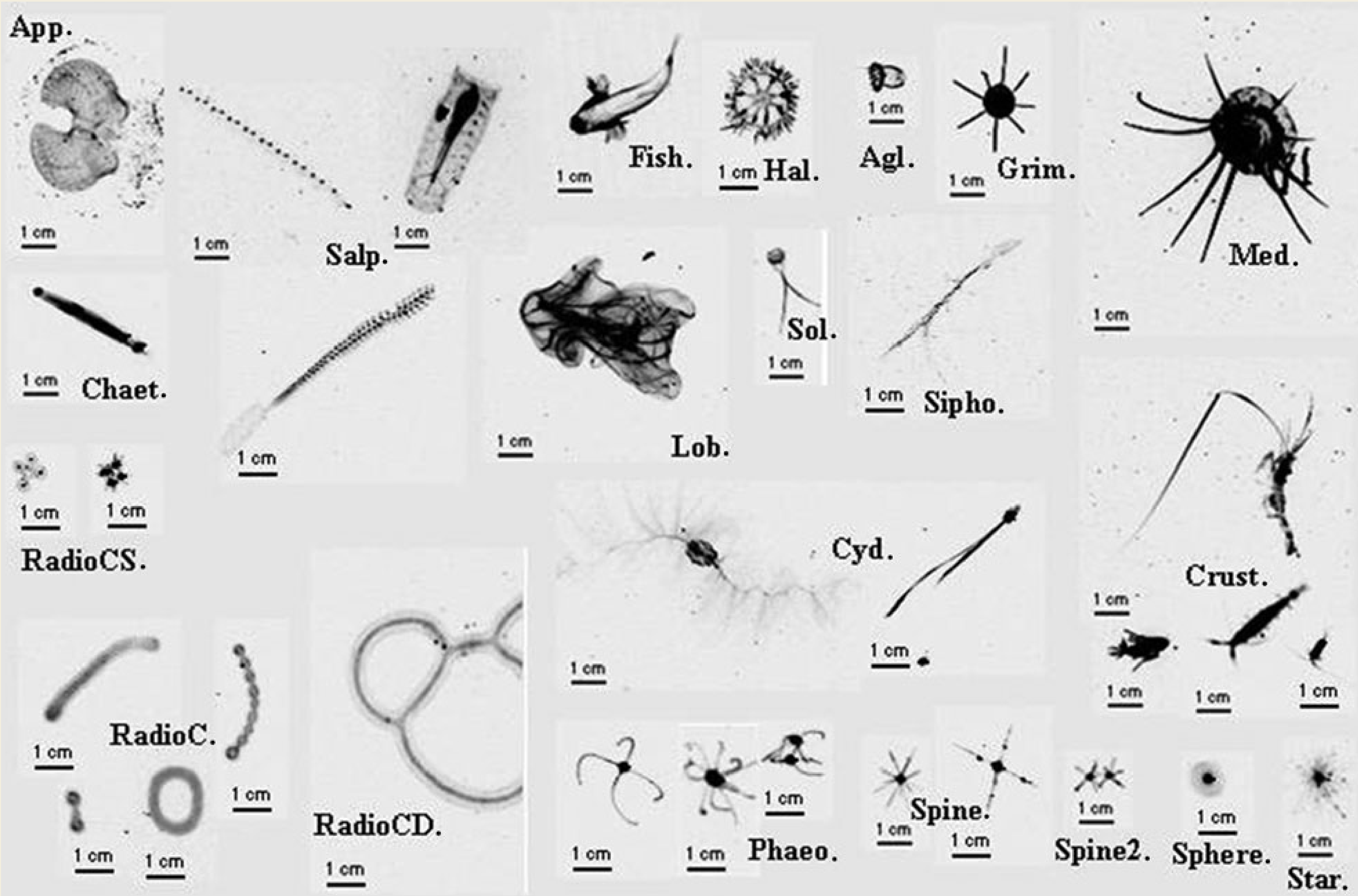
Nanoparticles



Verdugo, *Ann. Rev. Mar. Sci.*, 4:375–400,2012

Capturing Particles





Stemmann et al., *ICES J. Mar. Sci.,* 65:433–442, 2008

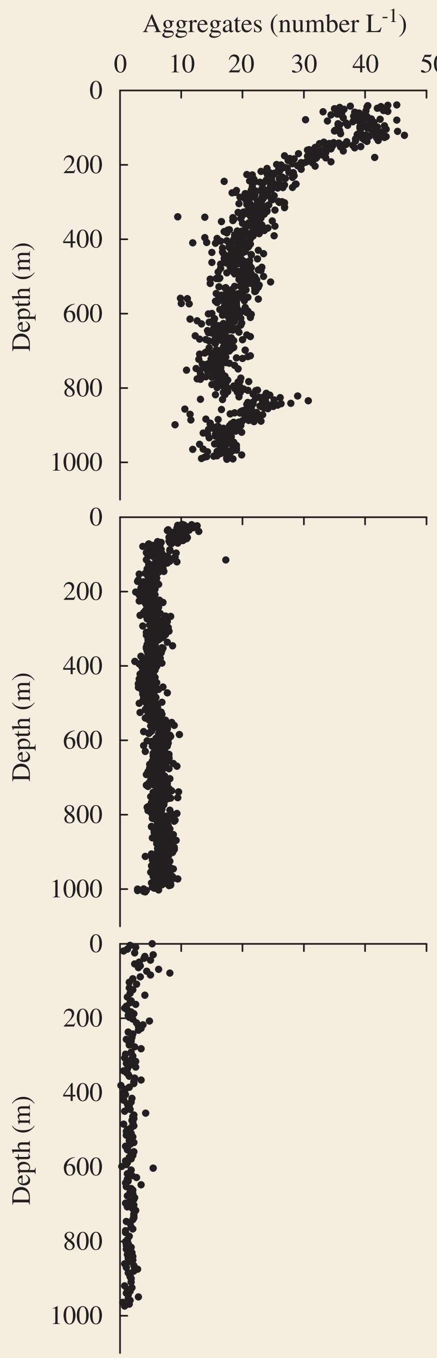
Particulate Flux

Particulate flux = Concentration × Settling Velocity

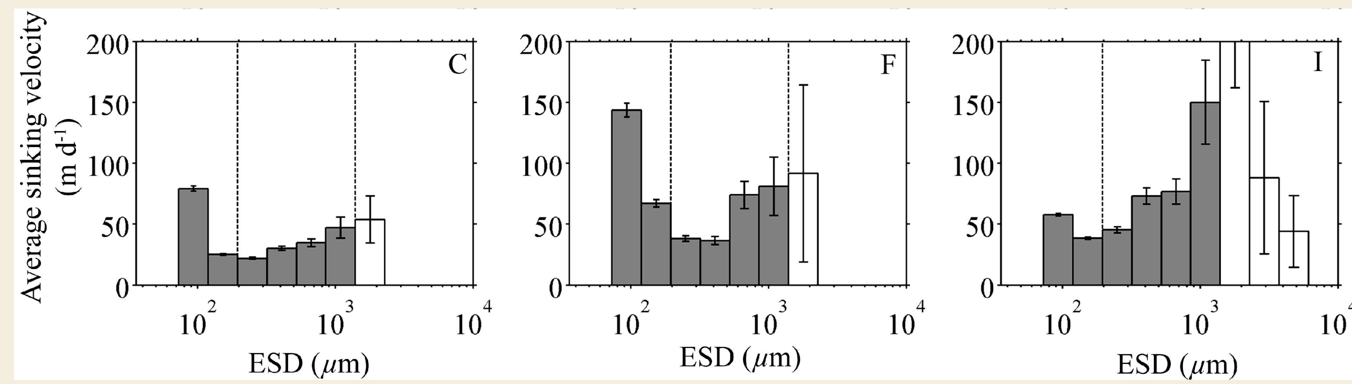
Southern Ocean

Eastern Atlantic

Equatorial Pacific

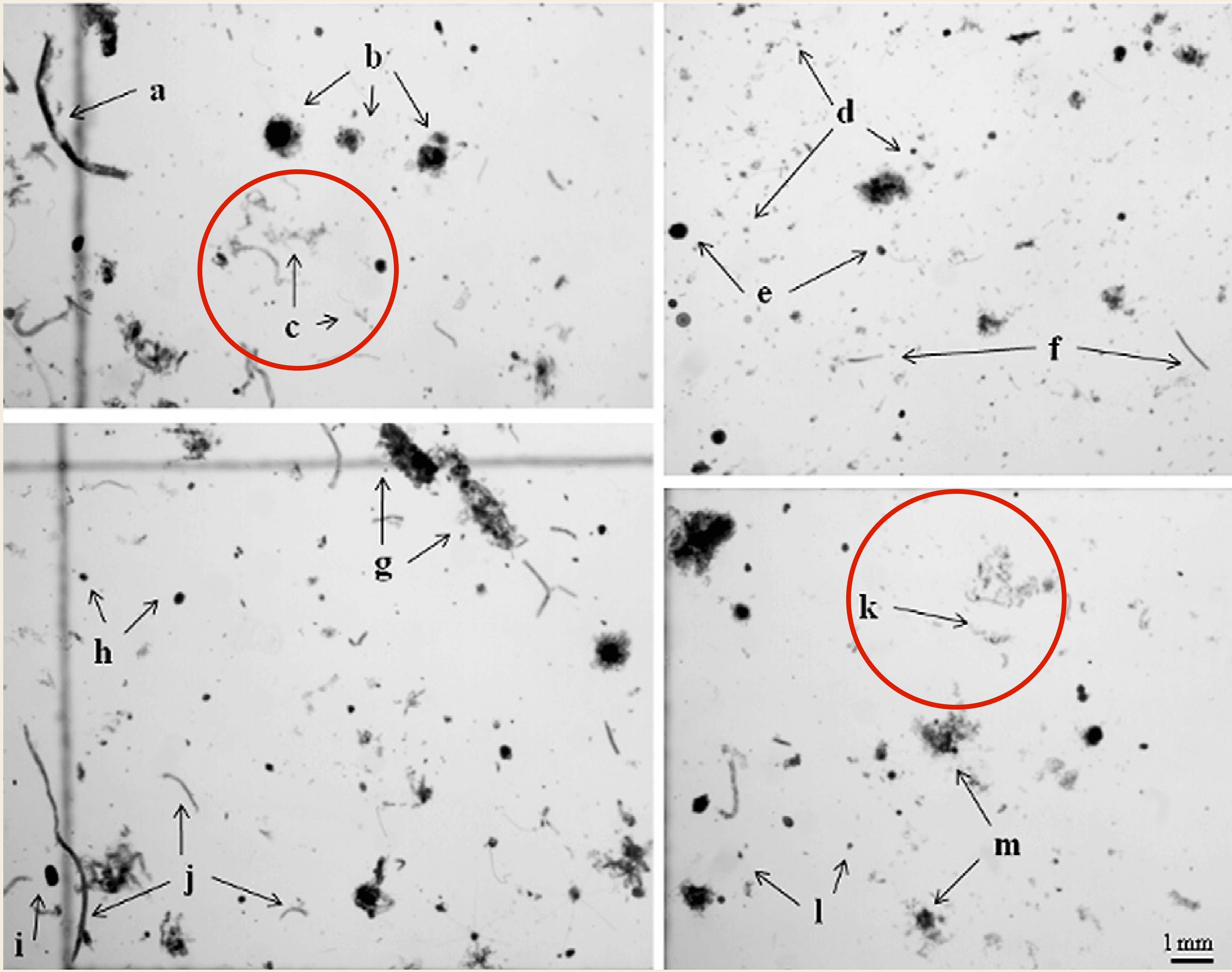


De La Rocha & Passow, *Deep-Sea Res. II,* 54:639–658, 2007

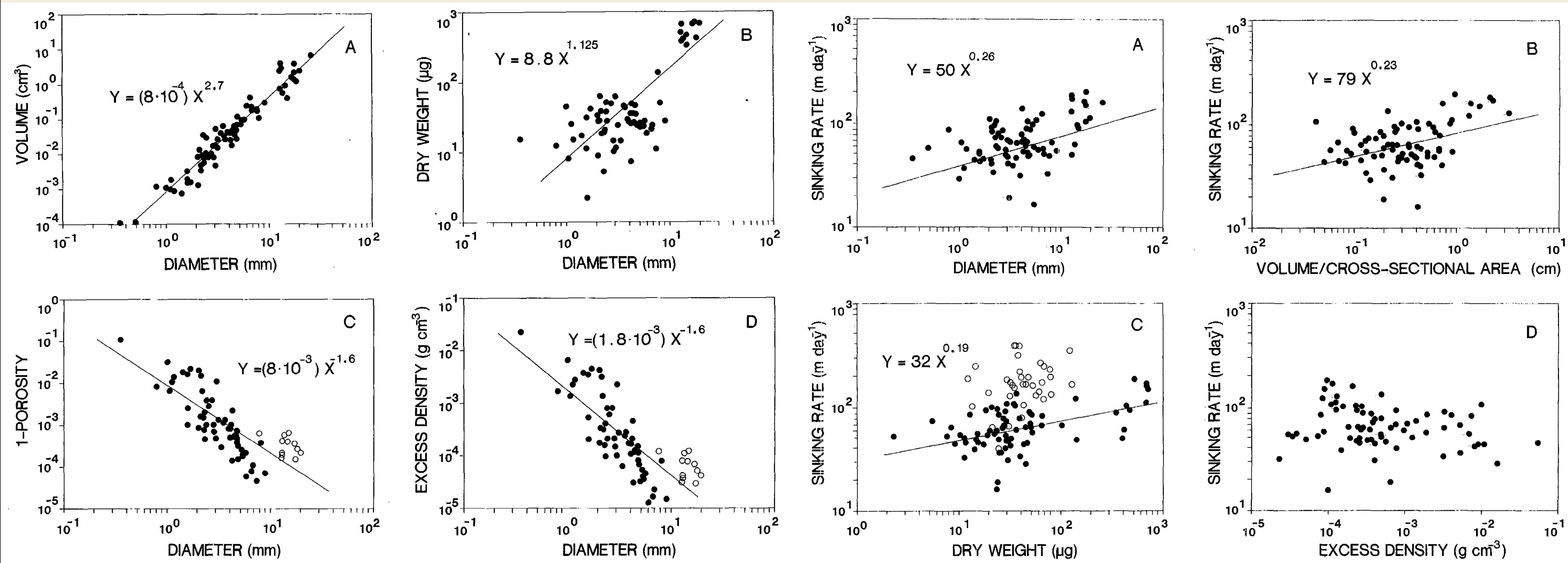


McDonnell & Buesseler, *Limnol. Oceanogr., 55:2085–2096,*2011

Particle type: fluffy aggregates

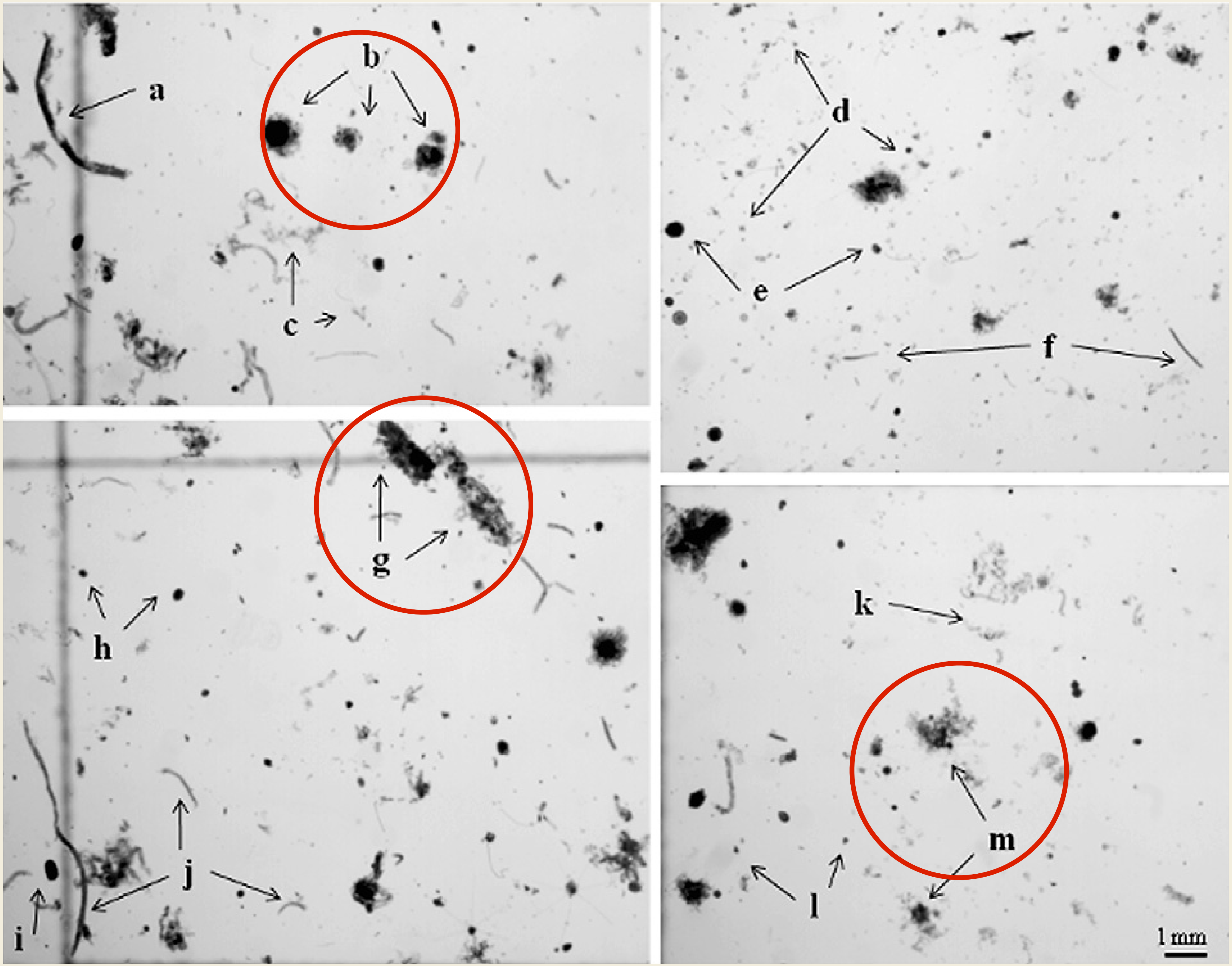


Ebersbach et al., *Deep-Sea Res. II*, 58:2260–2276, 2011



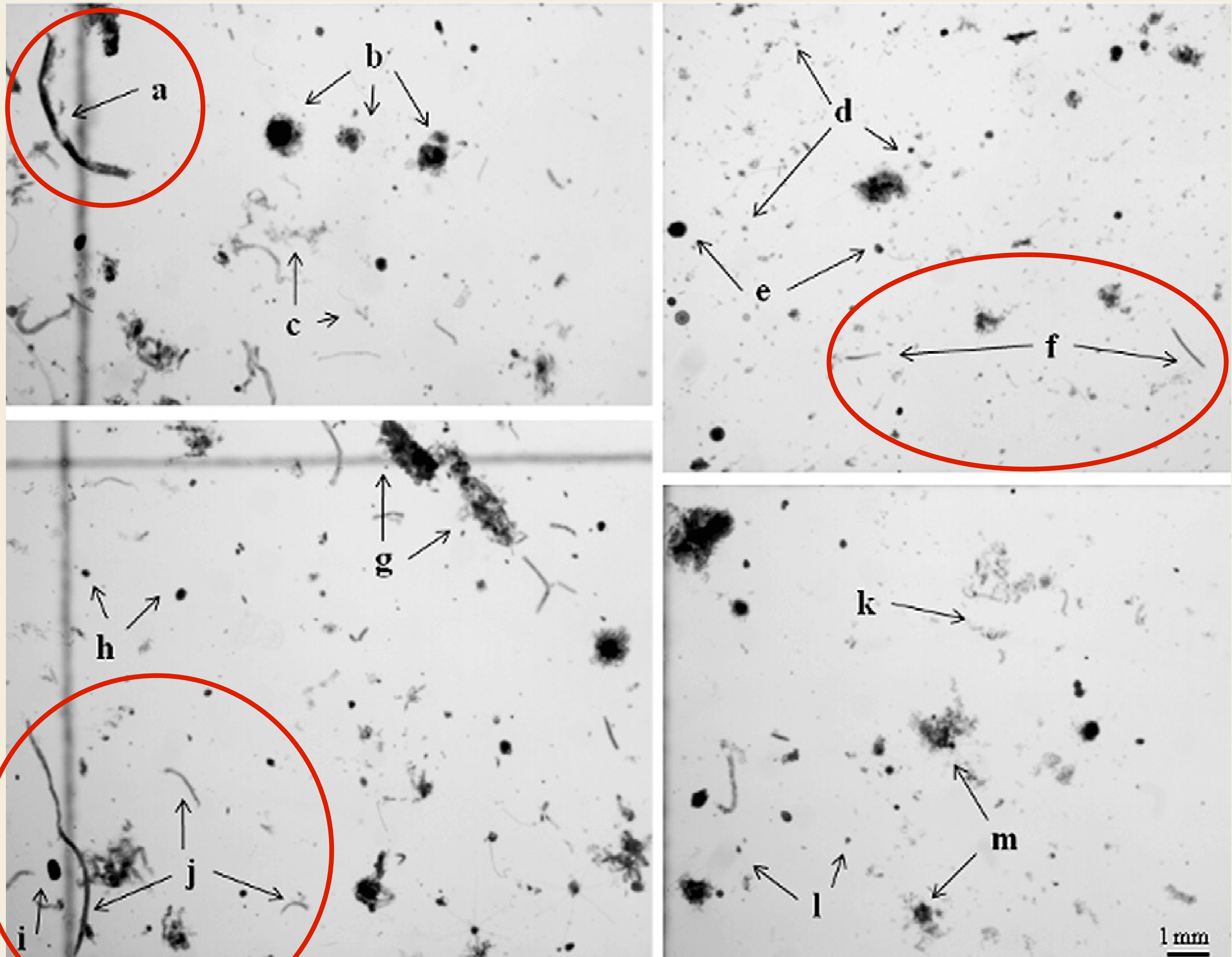
Alldredge & Gotschalk, *Limnol. Oceanogr.* 33:339–351,1988

Particle type: fecal aggregates



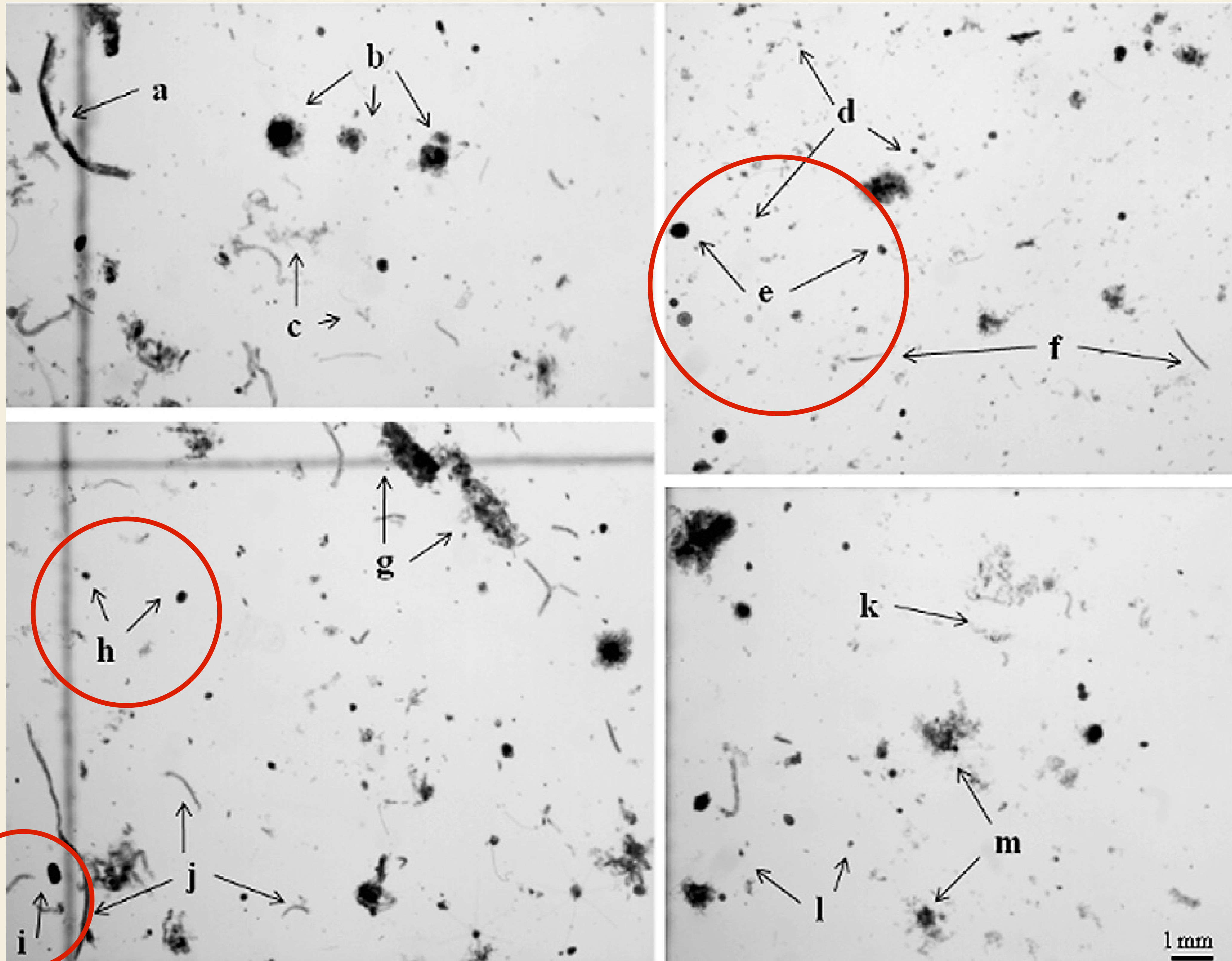
Ebersbach et al., *Deep-Sea Res. II*, 58:2260–2276, 2011

Particle type: cylindrical pellet

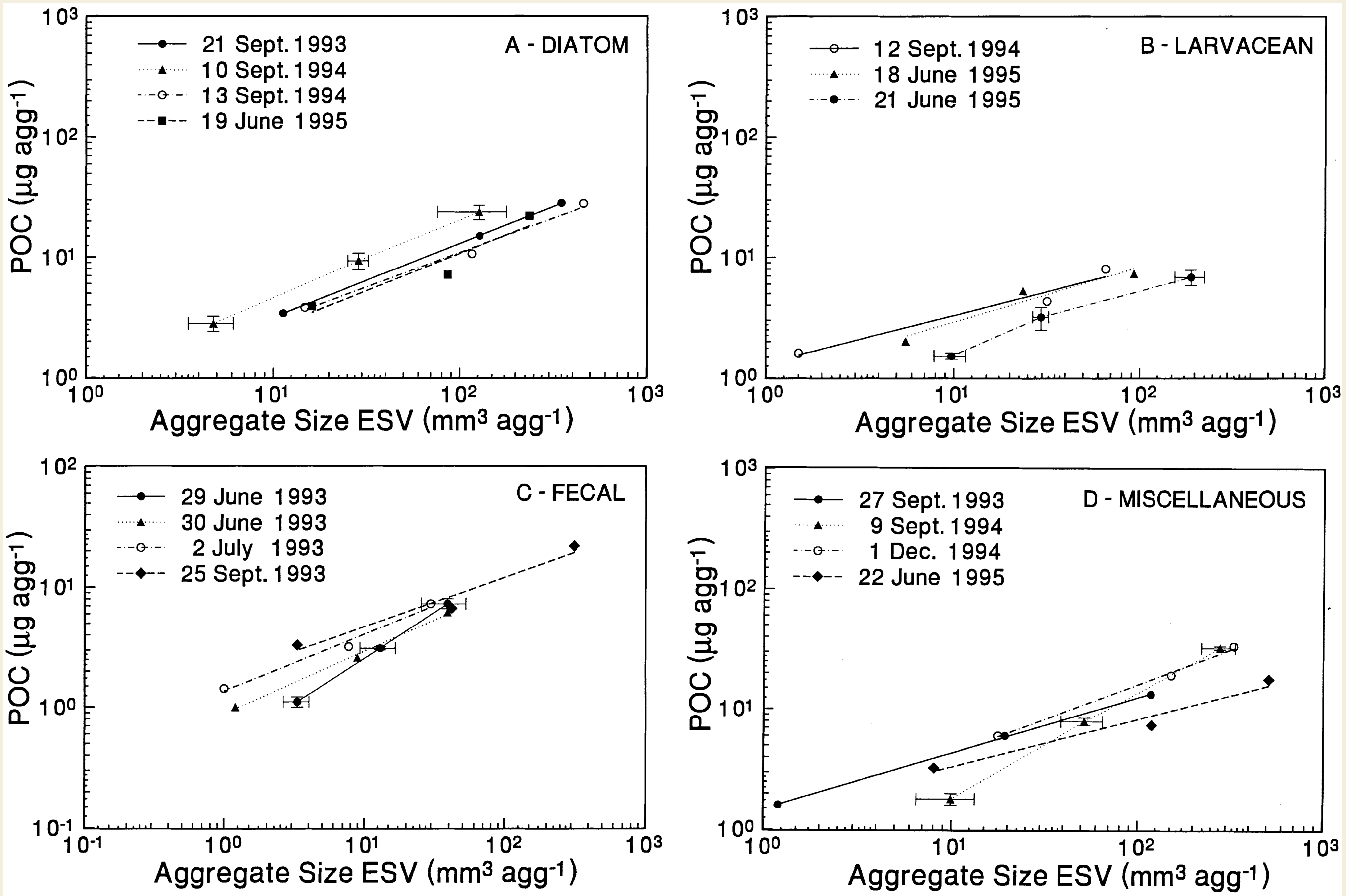


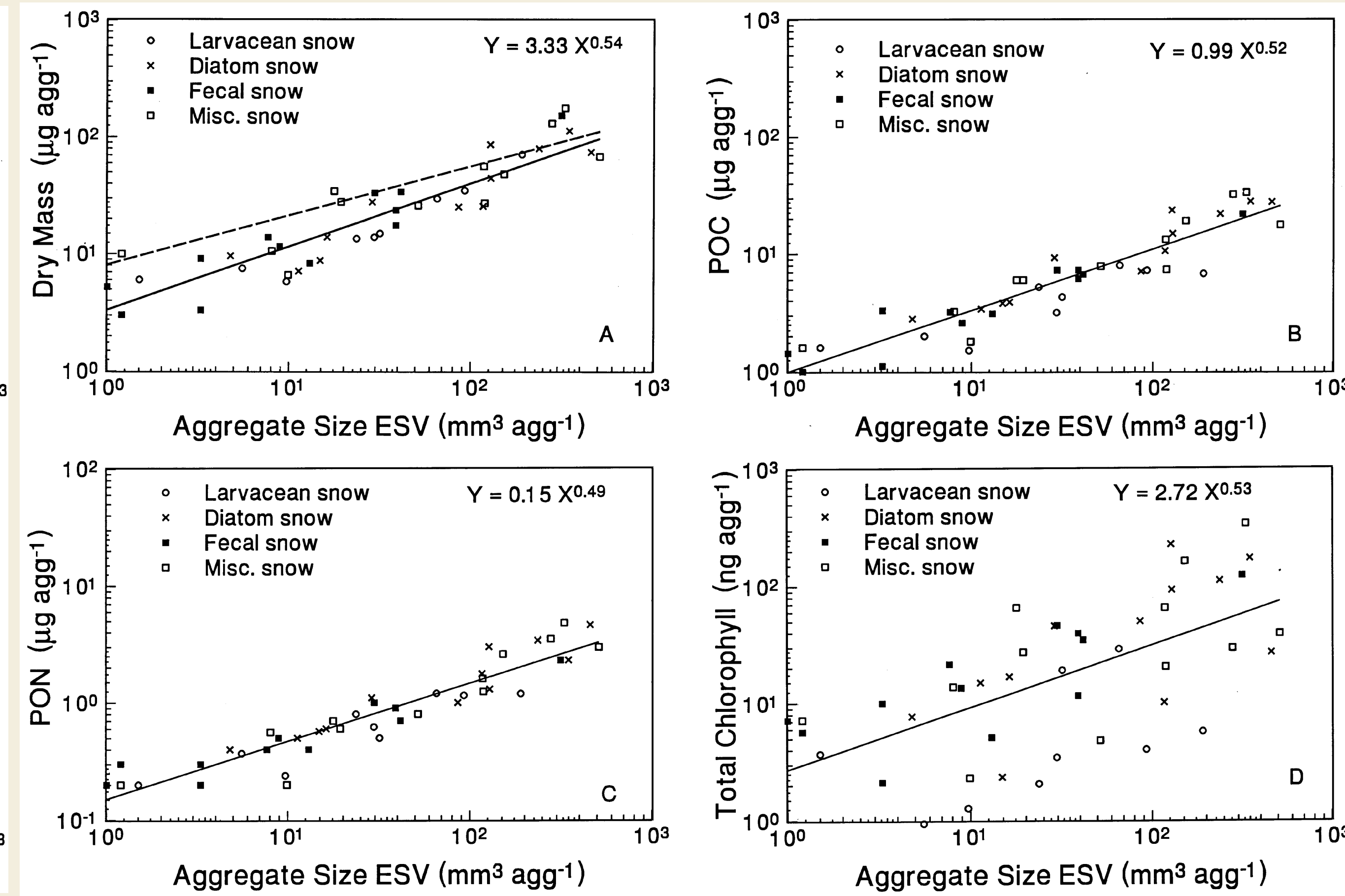
Ebersbach et al., *Deep-Sea Res. II*, 58:2260–2276, 2011

Particle type: ovoid pellet



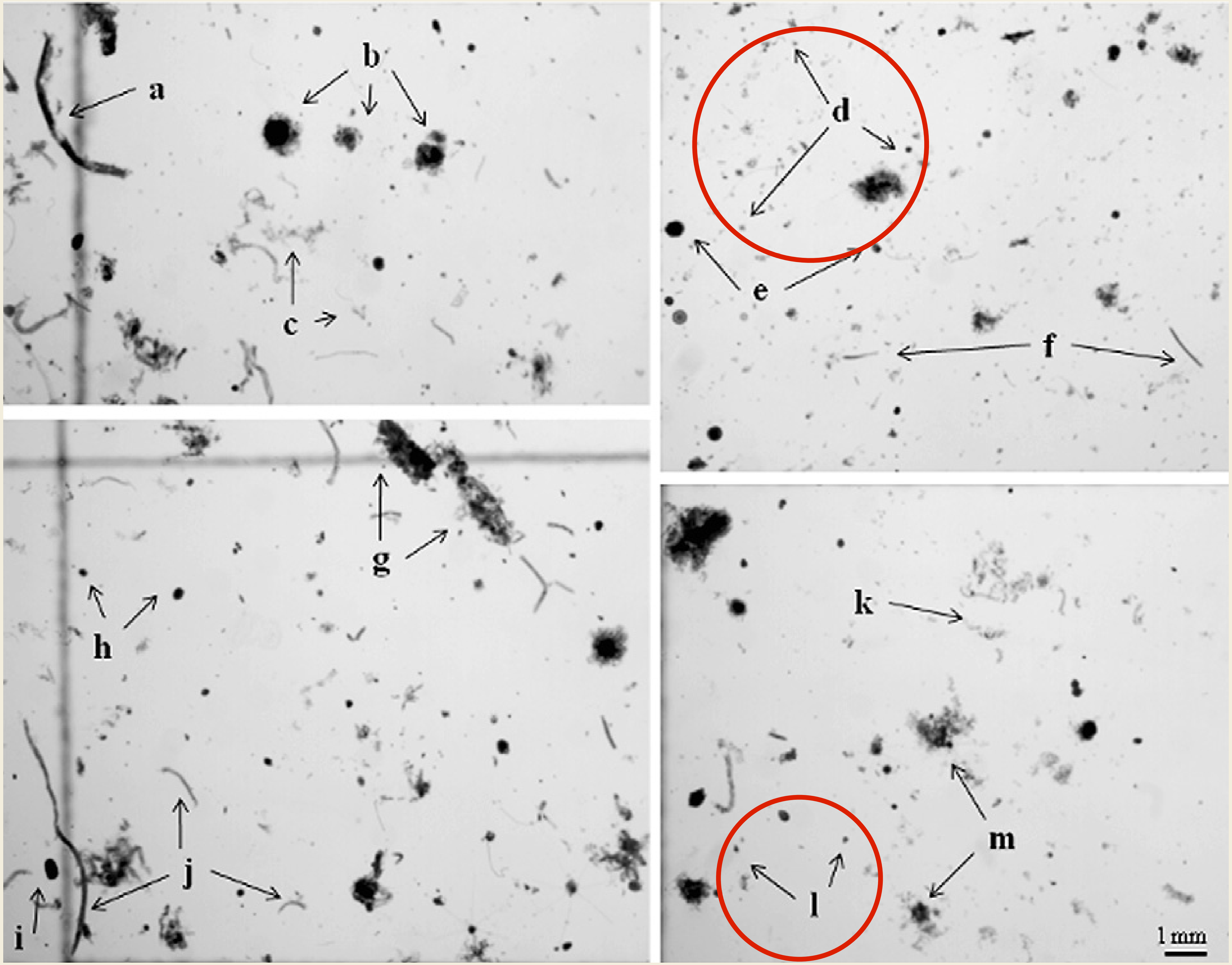
Ebersbach et al., *Deep-Sea Res. II*, 58:2260–2276, 2011





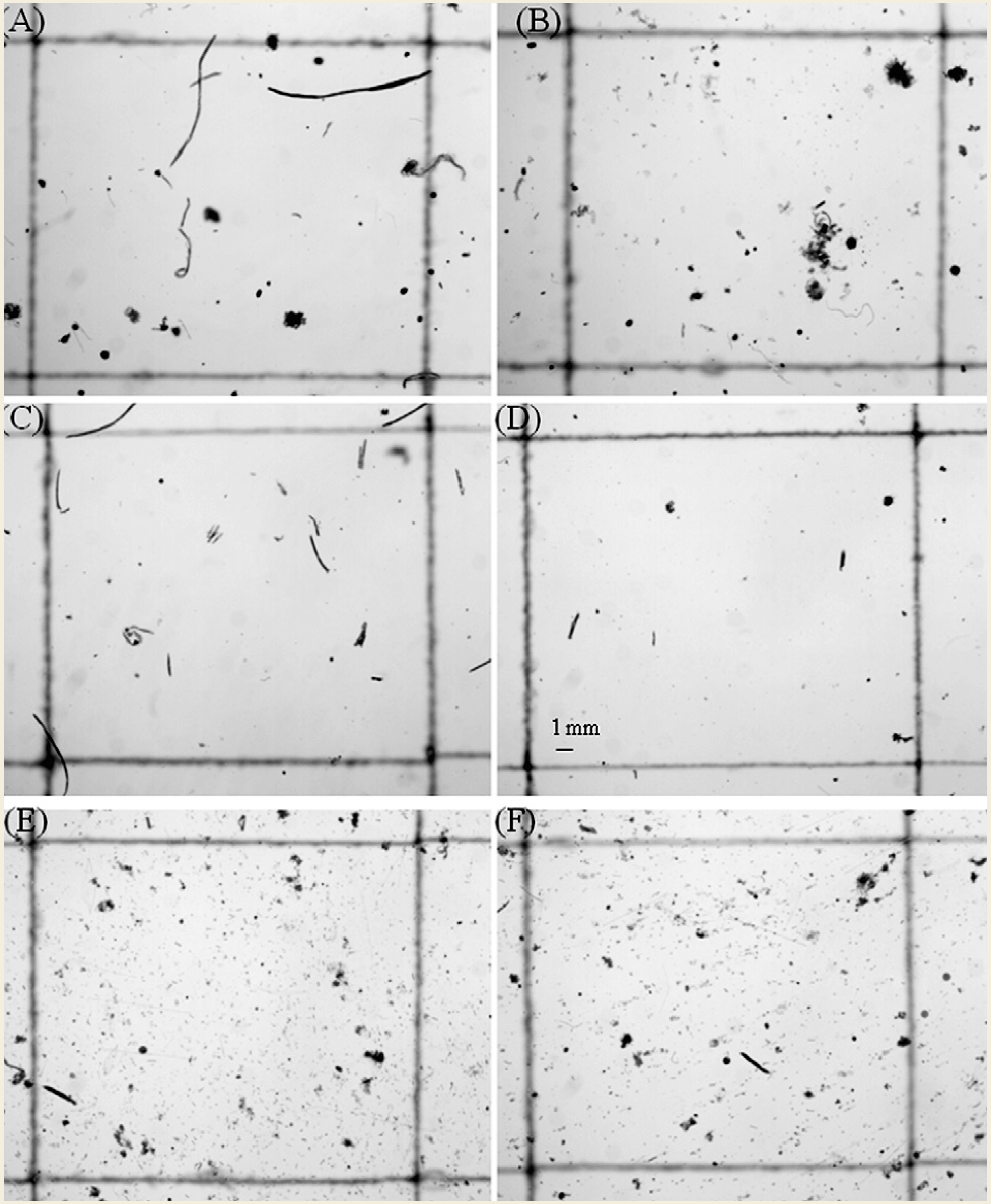
Alldredge, *Deep-Sea Res. I*, 45:529–541, 1998

Particle type: phyto cells

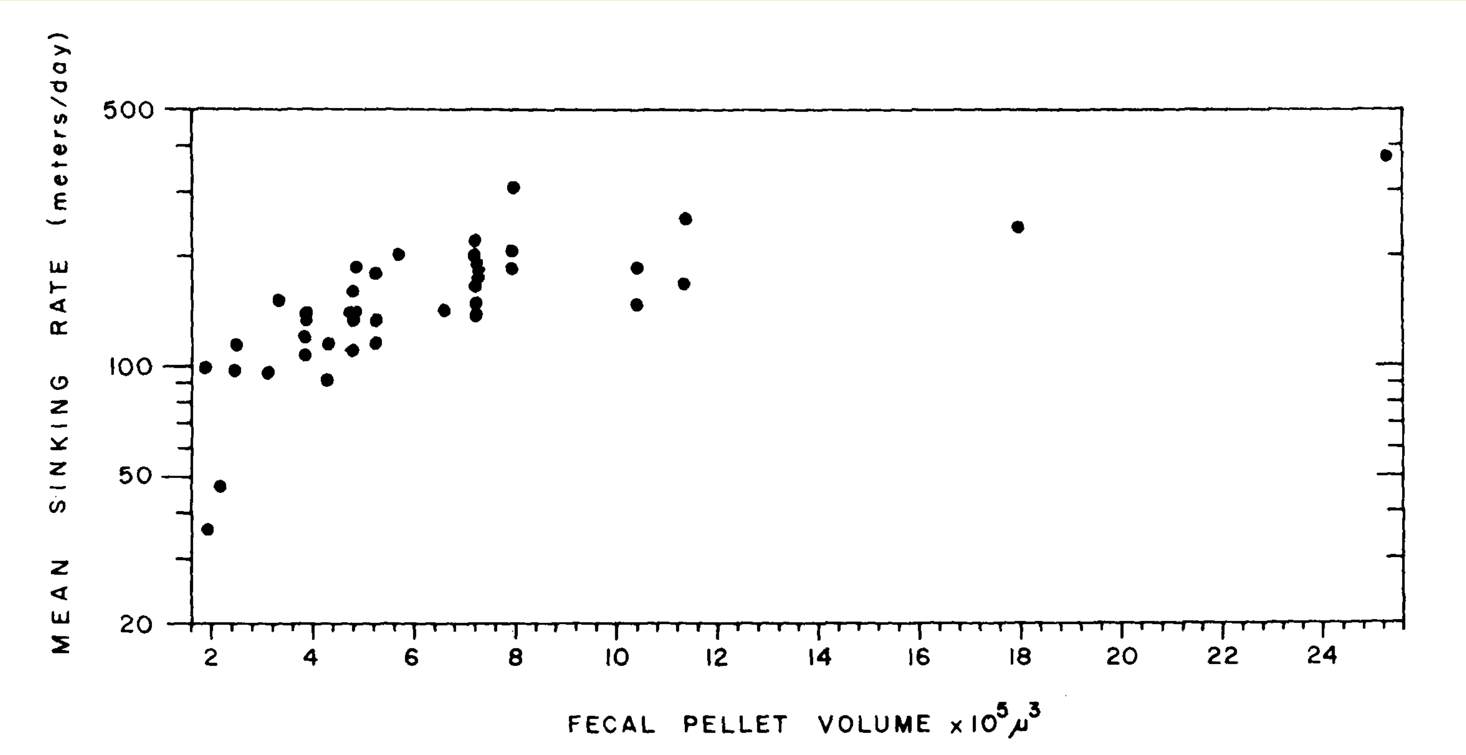


Ebersbach et al., *Deep-Sea Res. II*, 58:2260–2276, 2011

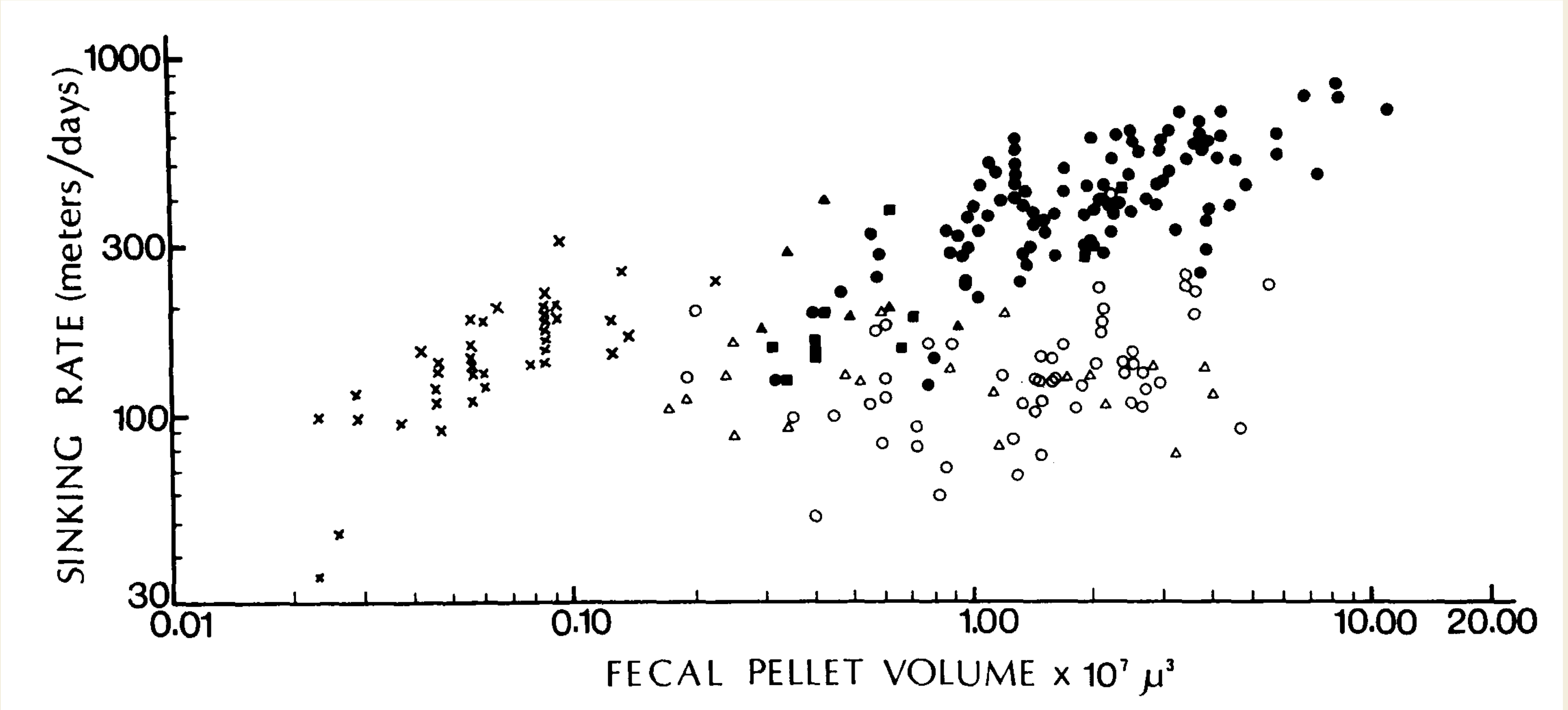
140 m   290 m



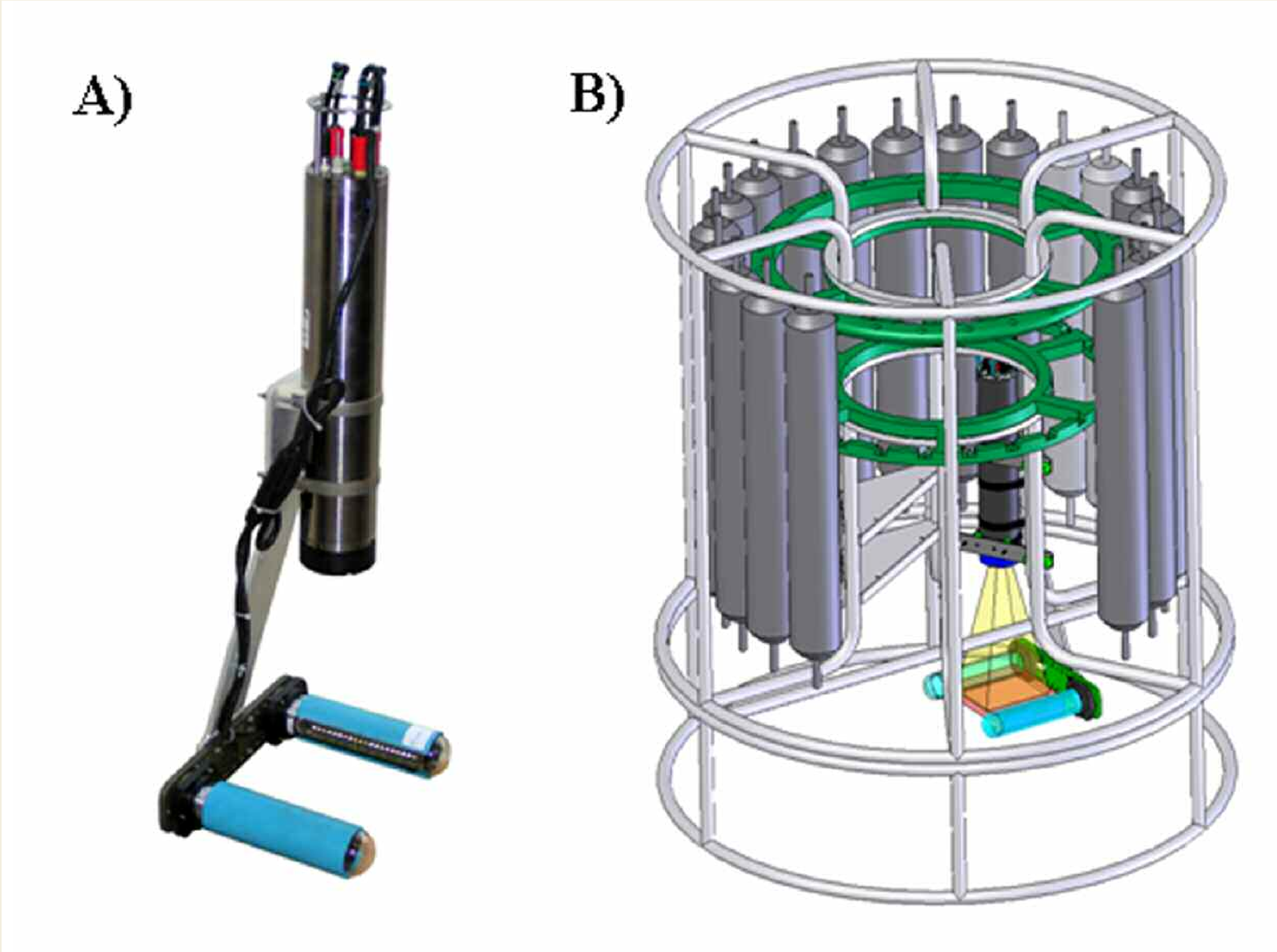
Ebersbach et al., *Deep-Sea Res. II*, 58:2260–2276, 2011



Smayda, *Limnol. Oceanogr.* 14:621–625, 1969

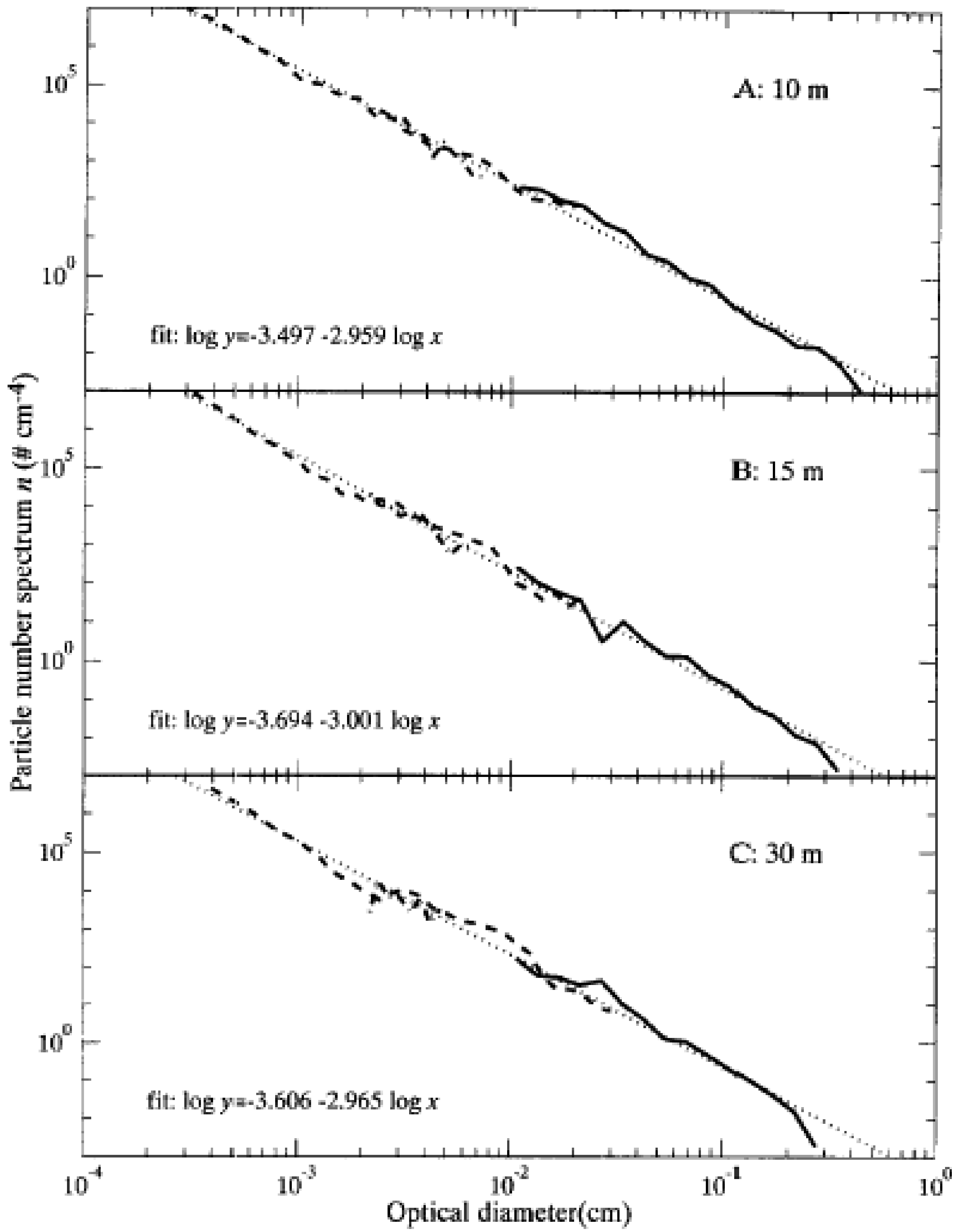


Fowler & Small, *Limnol. Oceanogr., 17:293–296, 1972*



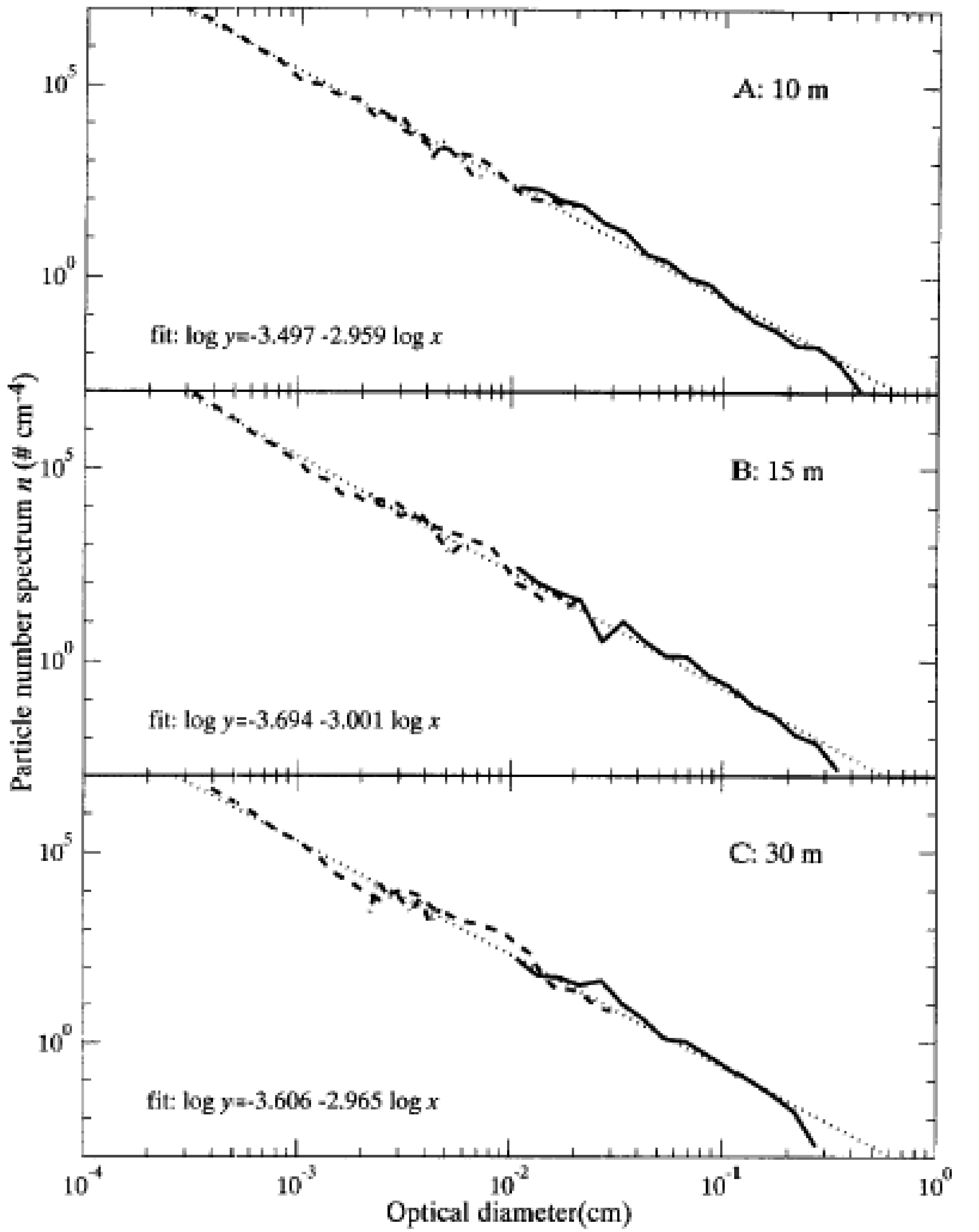
Picheral et al., *Limnol. Oceanogr. Methods,* 8:462–473, 2010

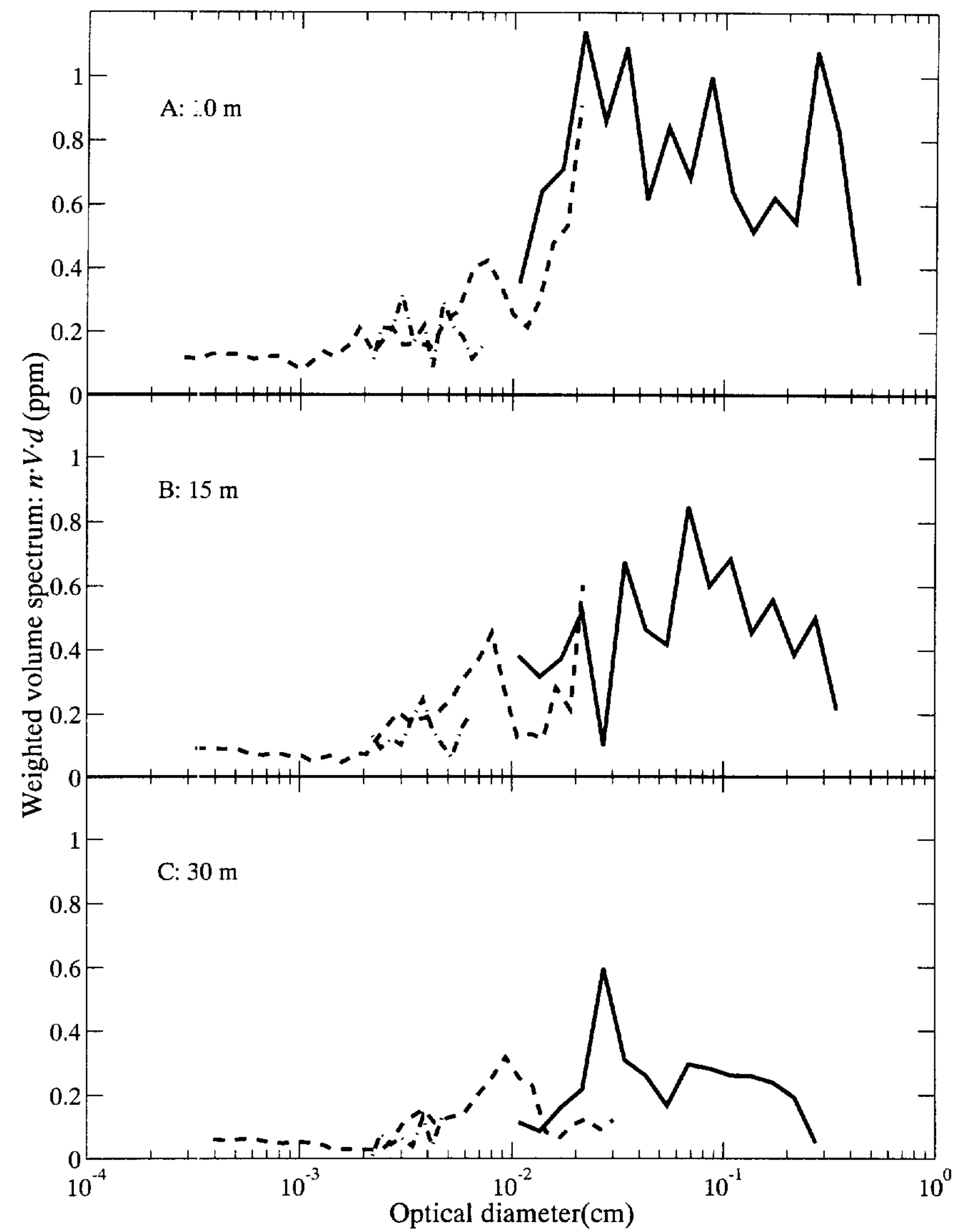
Particle Size Spectra



Jackson et al., *Deep-Sea Res.* 1997

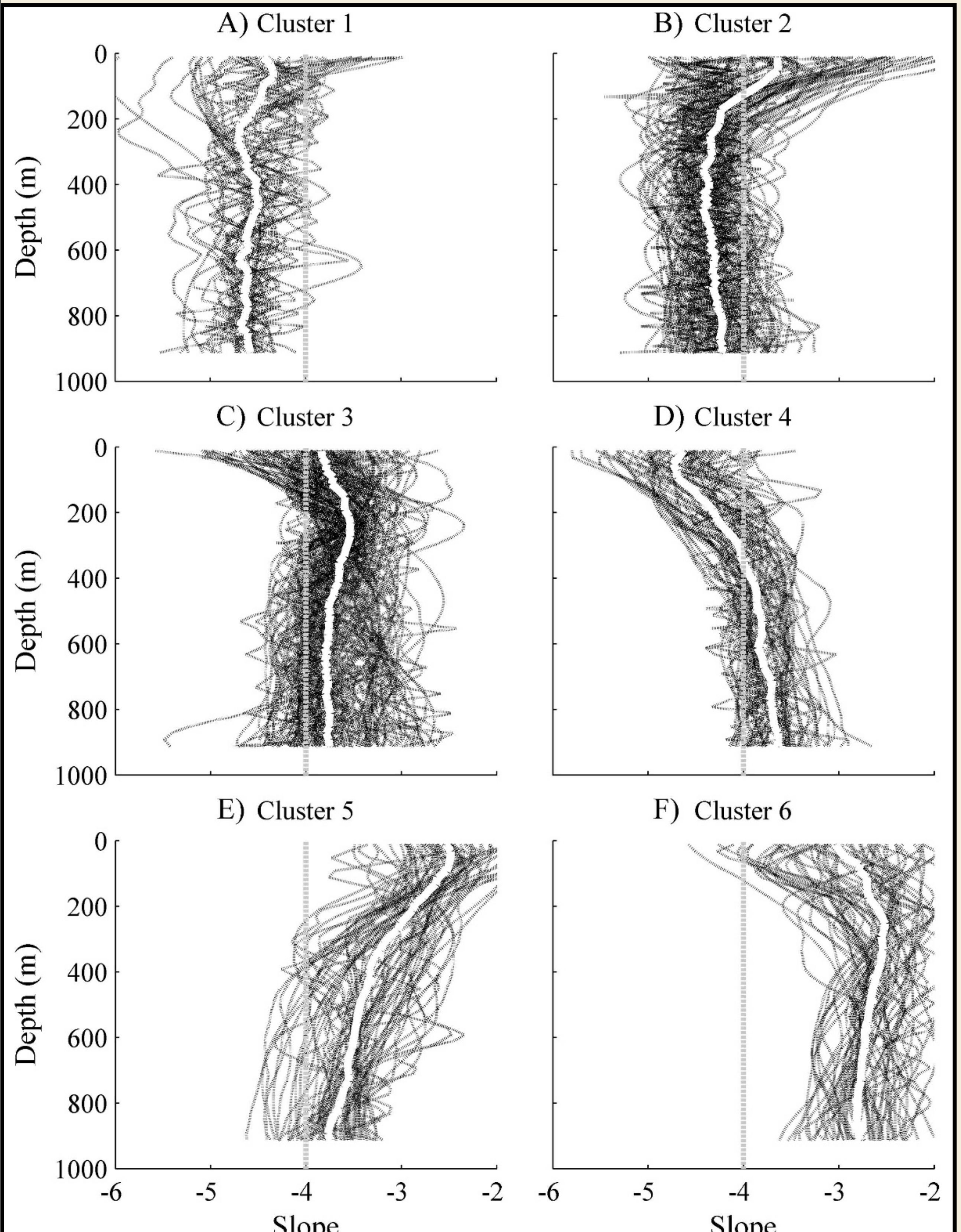
Particle Size Spectra

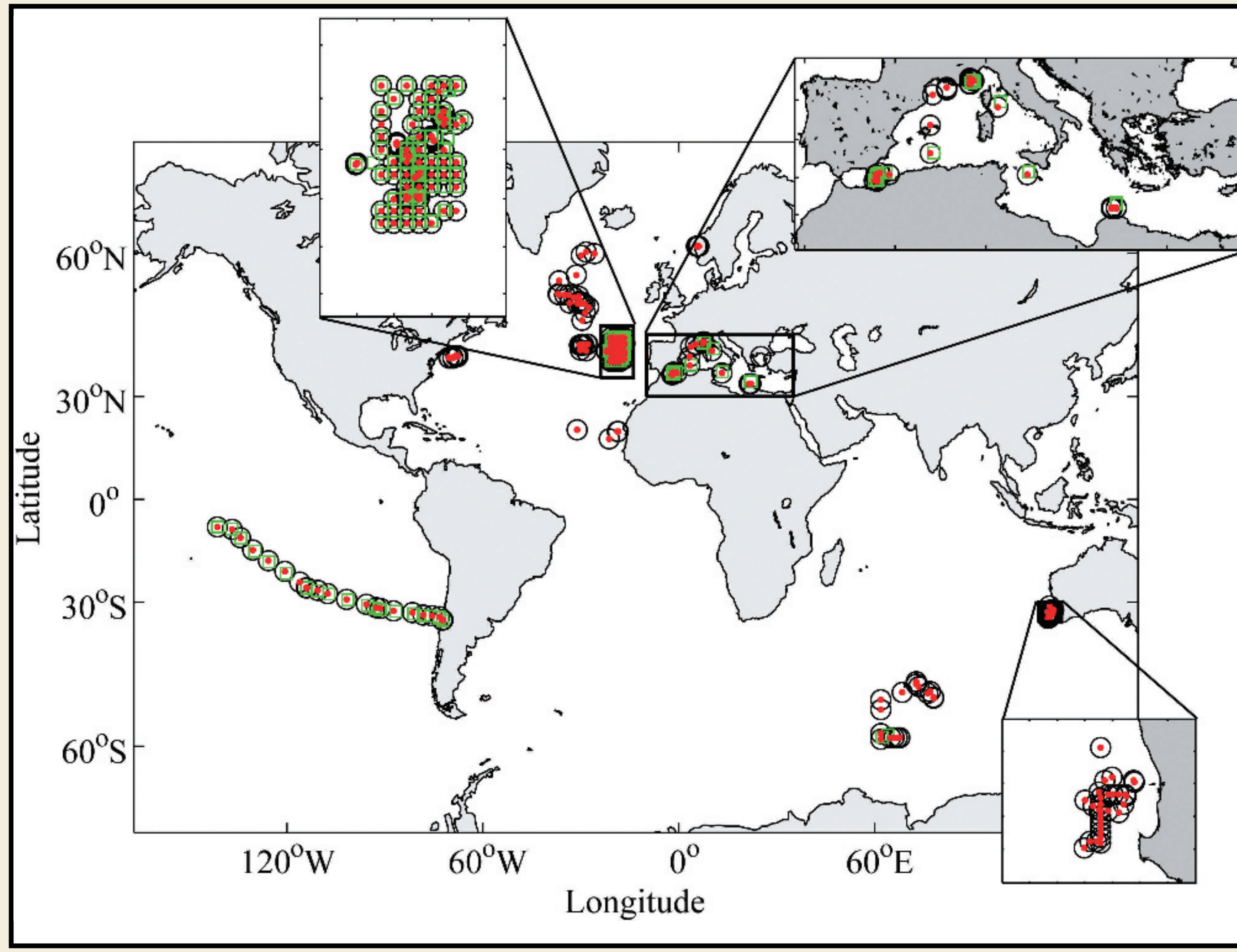




Jackson et al., *Deep-Sea Res.* 1997

Variations in spectral slope

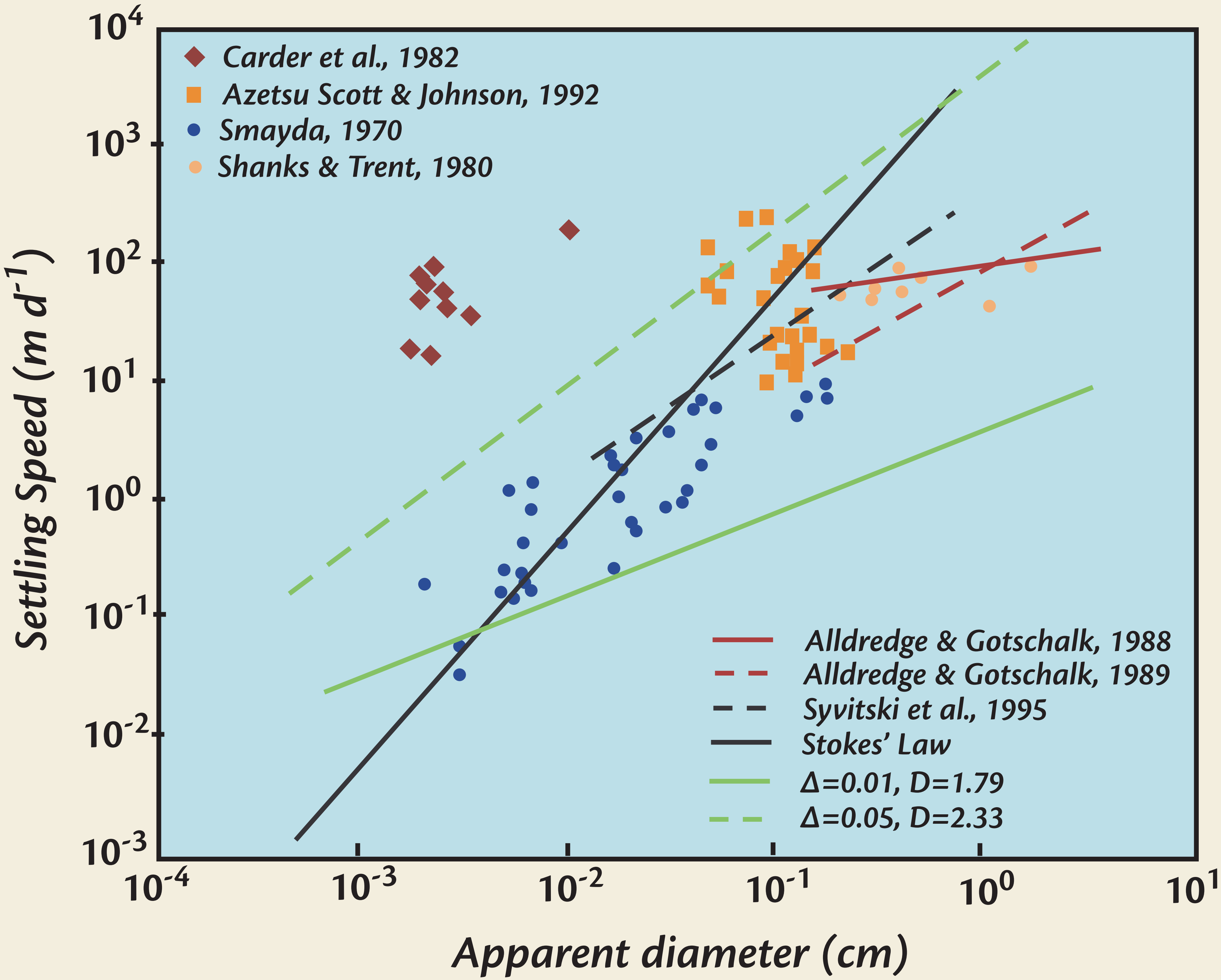




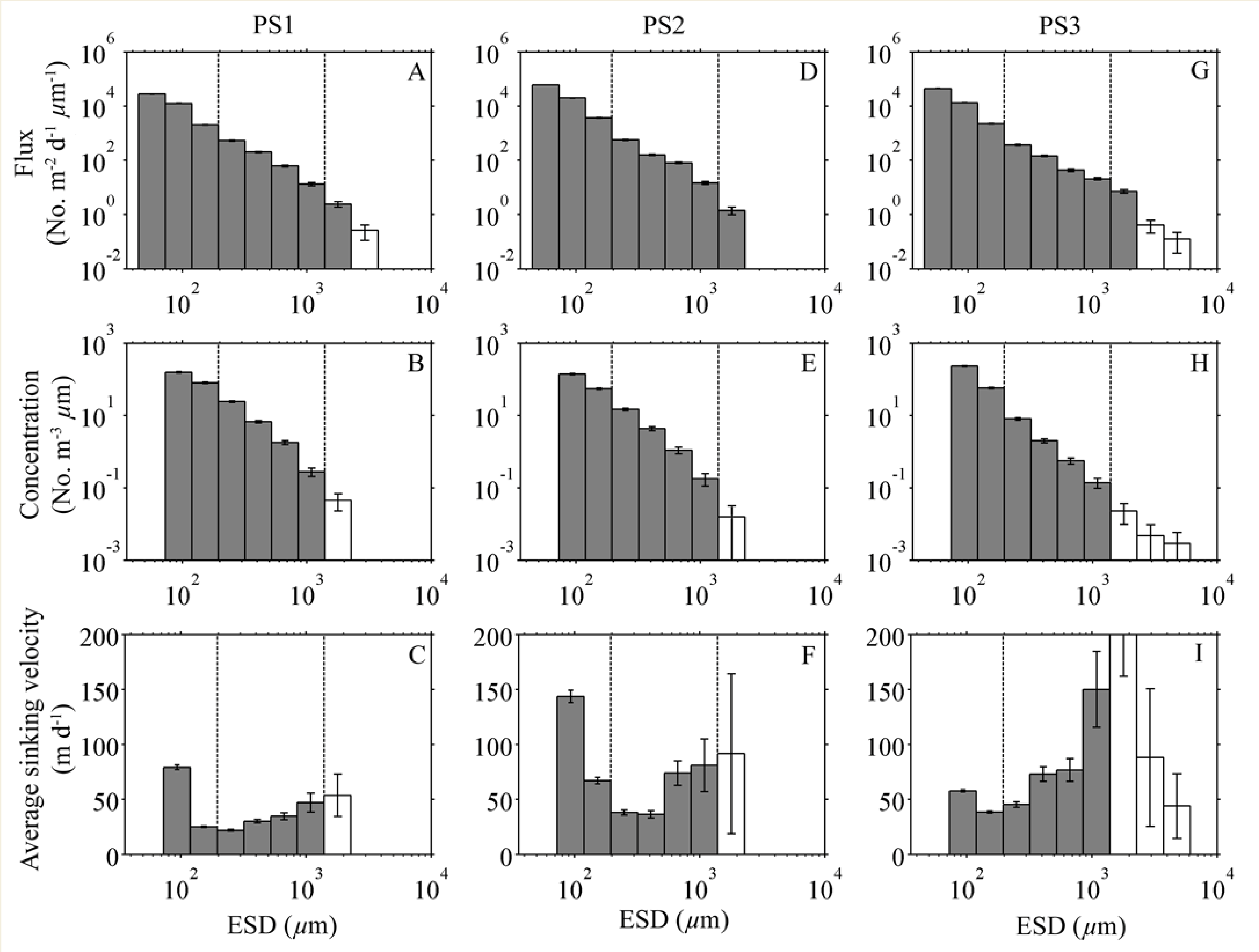
$$n(r) = ar^{-b}$$

Guidi et al., *Limnology & Oceanogr.,* 2009

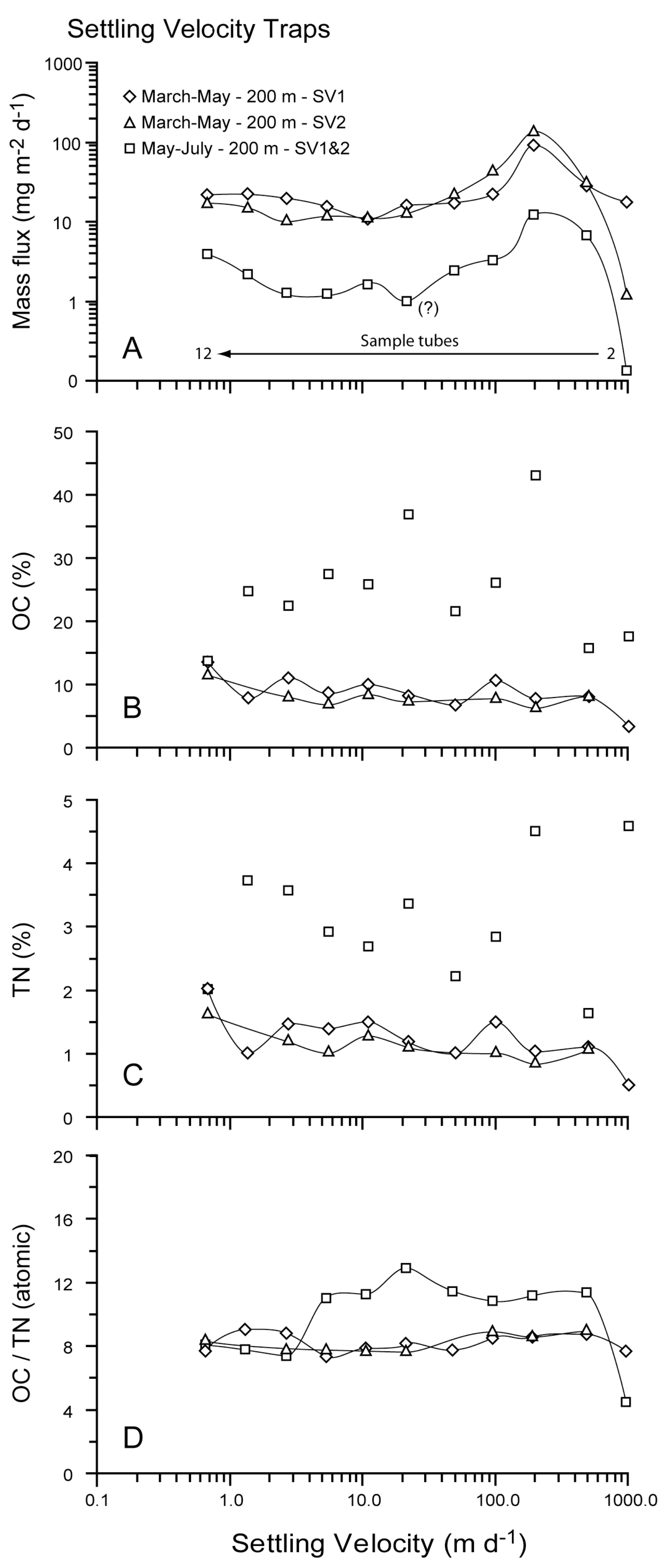
Settling Velocity



Stemmann et al., 2004



McDonnell & Buesseler, *Limnol. Oceanogr., 55:2085–2096,*2011

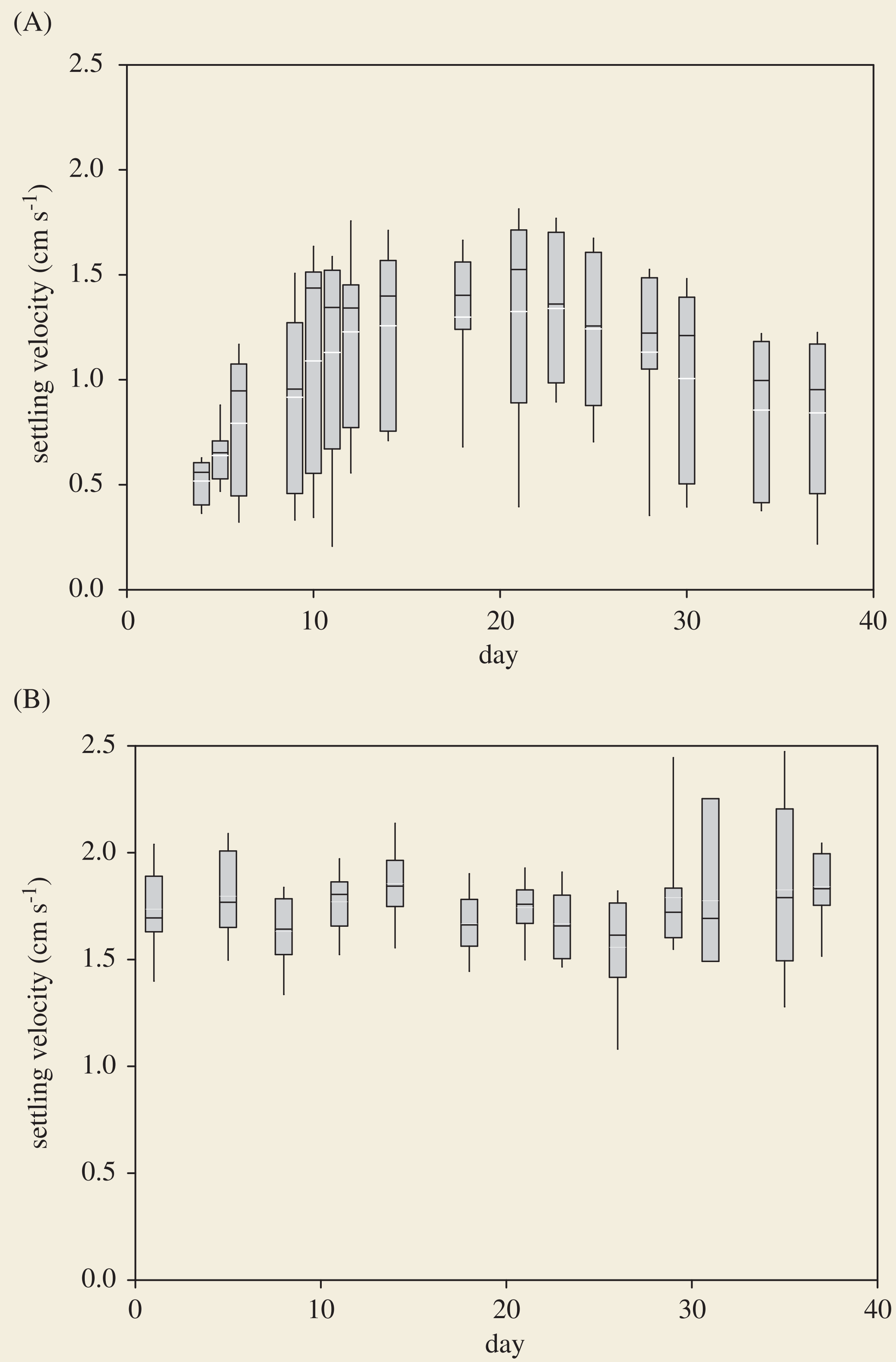


Peterson et al., *Limnol. Oceanogr. Methods, 3:520–532,* 2005

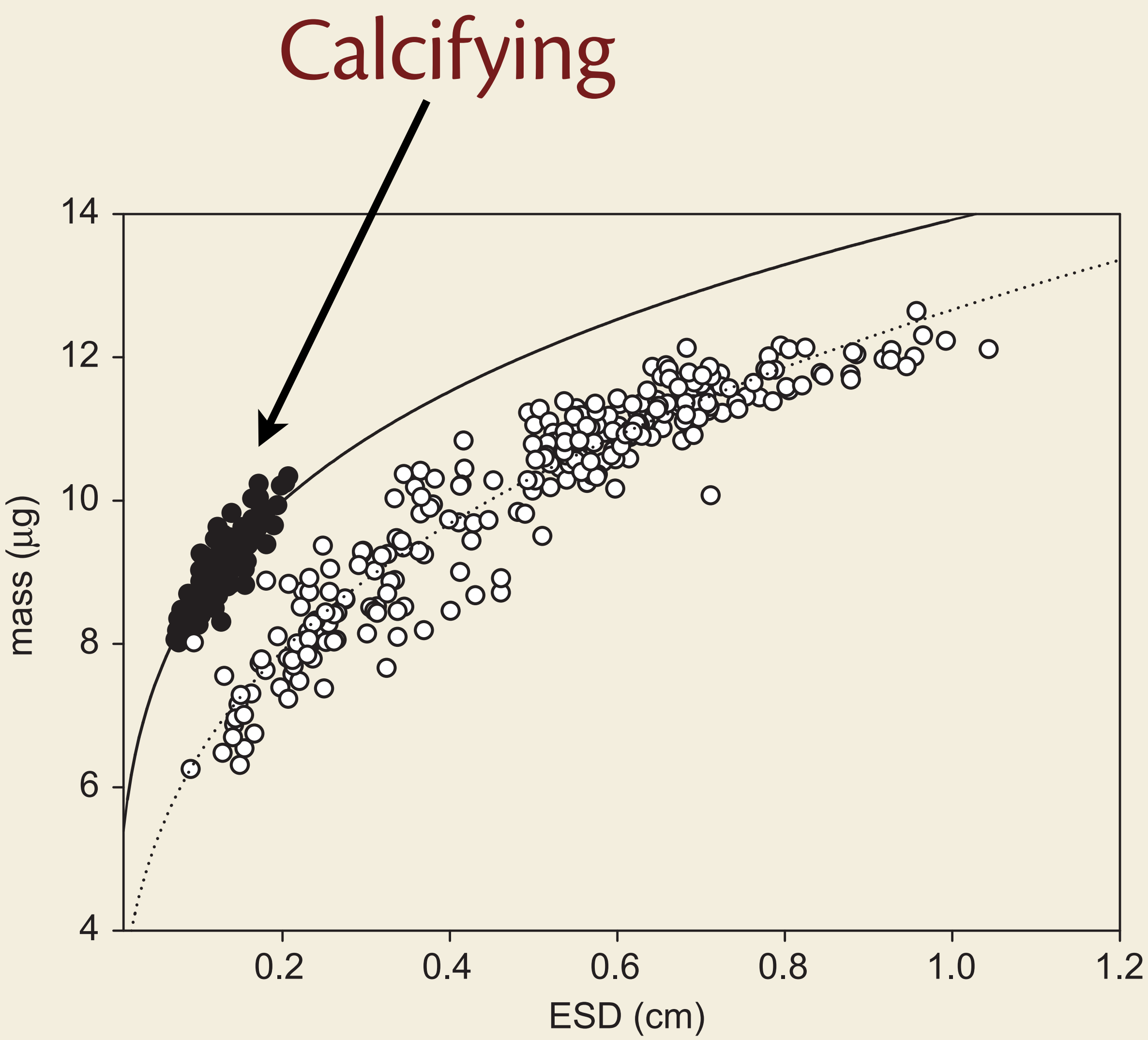
Wednesday, August 7, 13

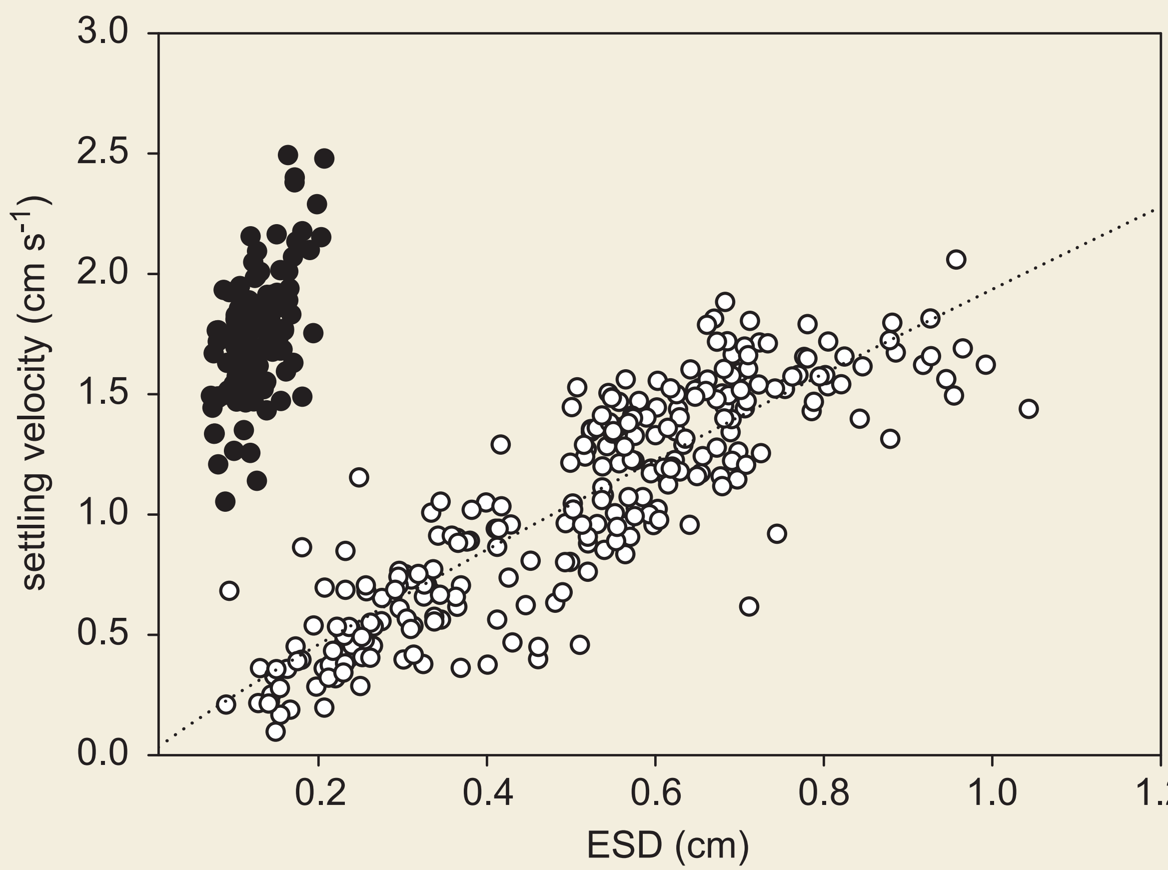
Non-calcifying

Calcifying



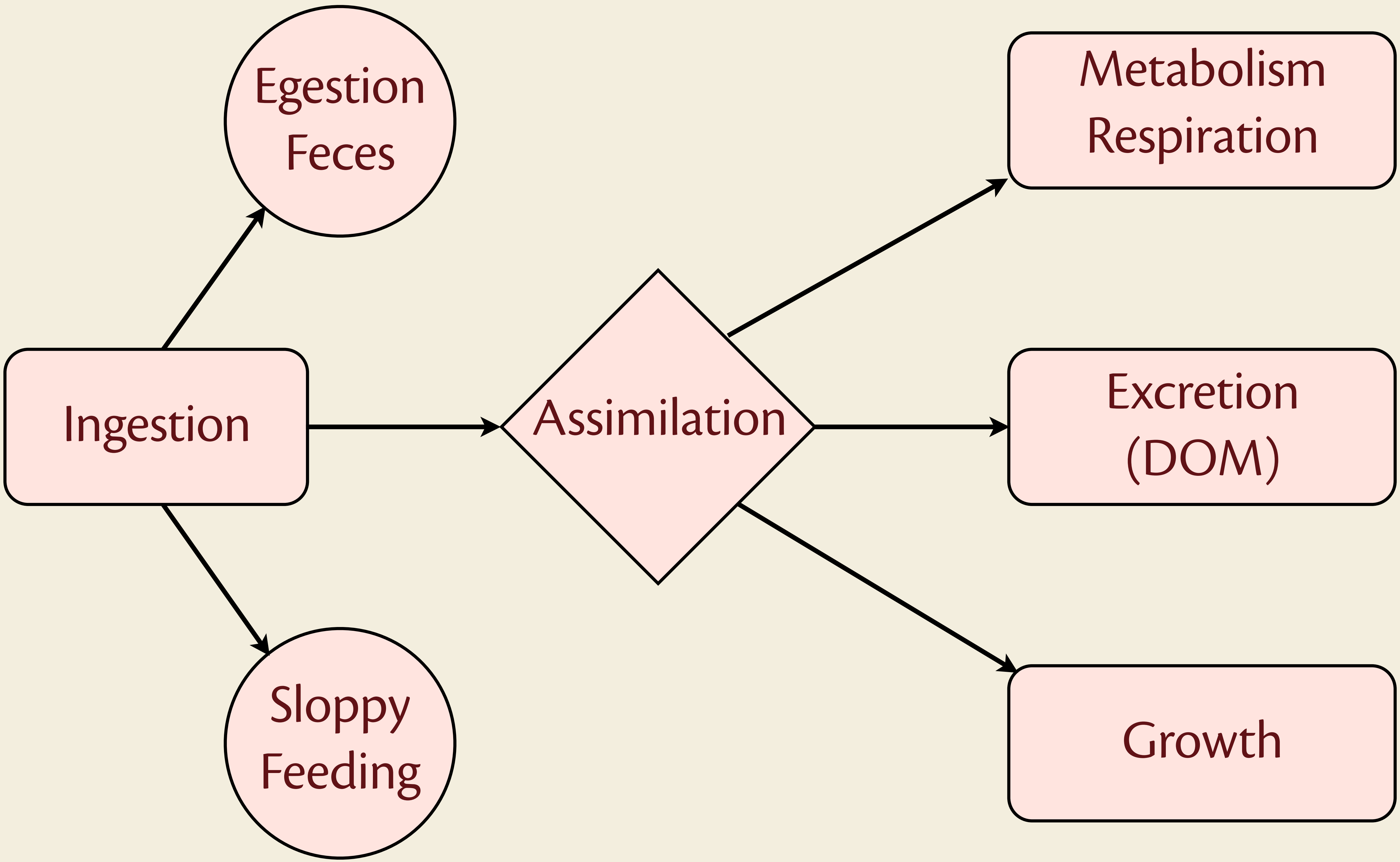
Engel et al., *Deep-Sea Res. II,* 56:1396–1407, 2009





Engel et al., *Deep-Sea Res. II,* 56:1396–1407, 2009

Zooplankton



Vertical Migration

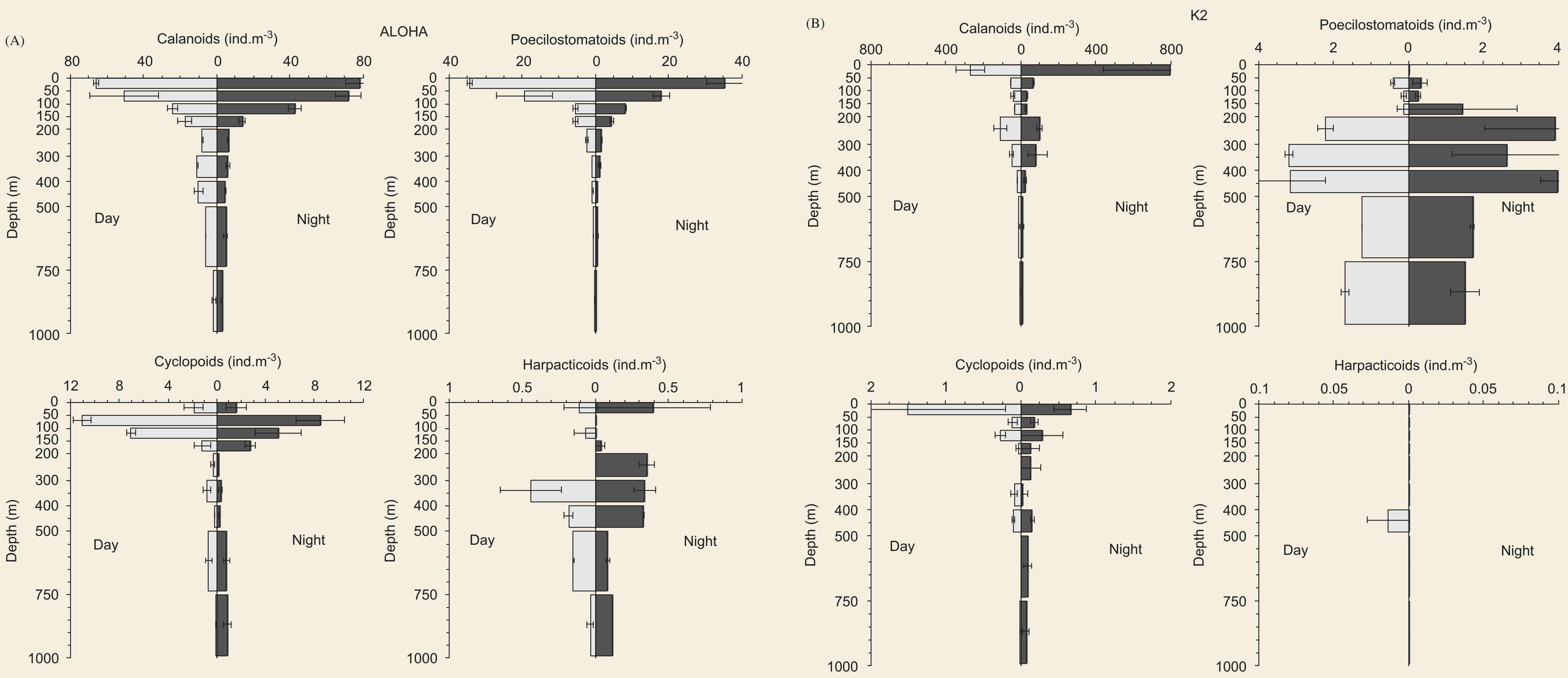
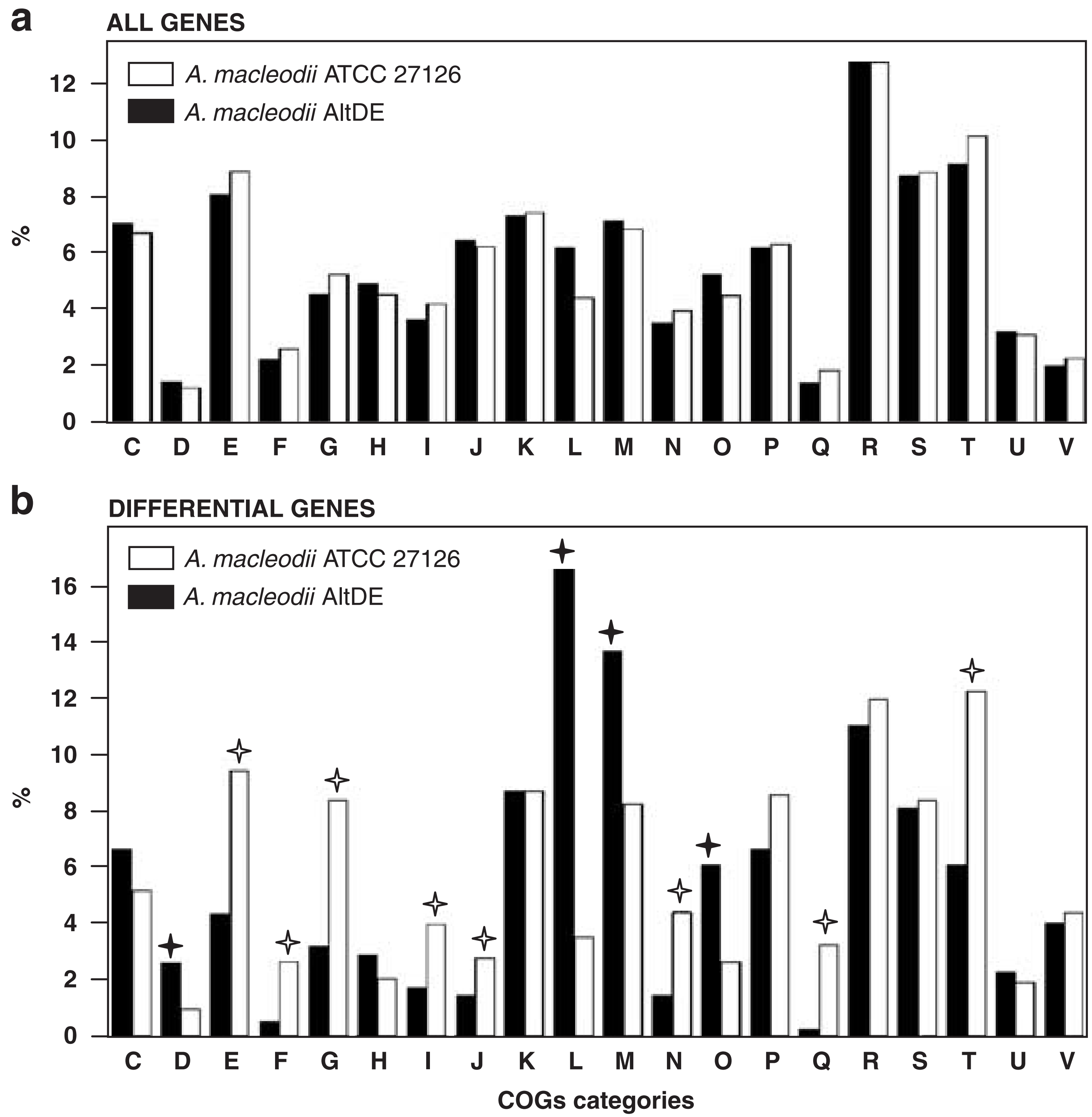


Fig. 3. (*Continued*)

Steinberg et al., *Deep-Sea Res. II, 55:1615–1635, 2008*

Microbial Processes

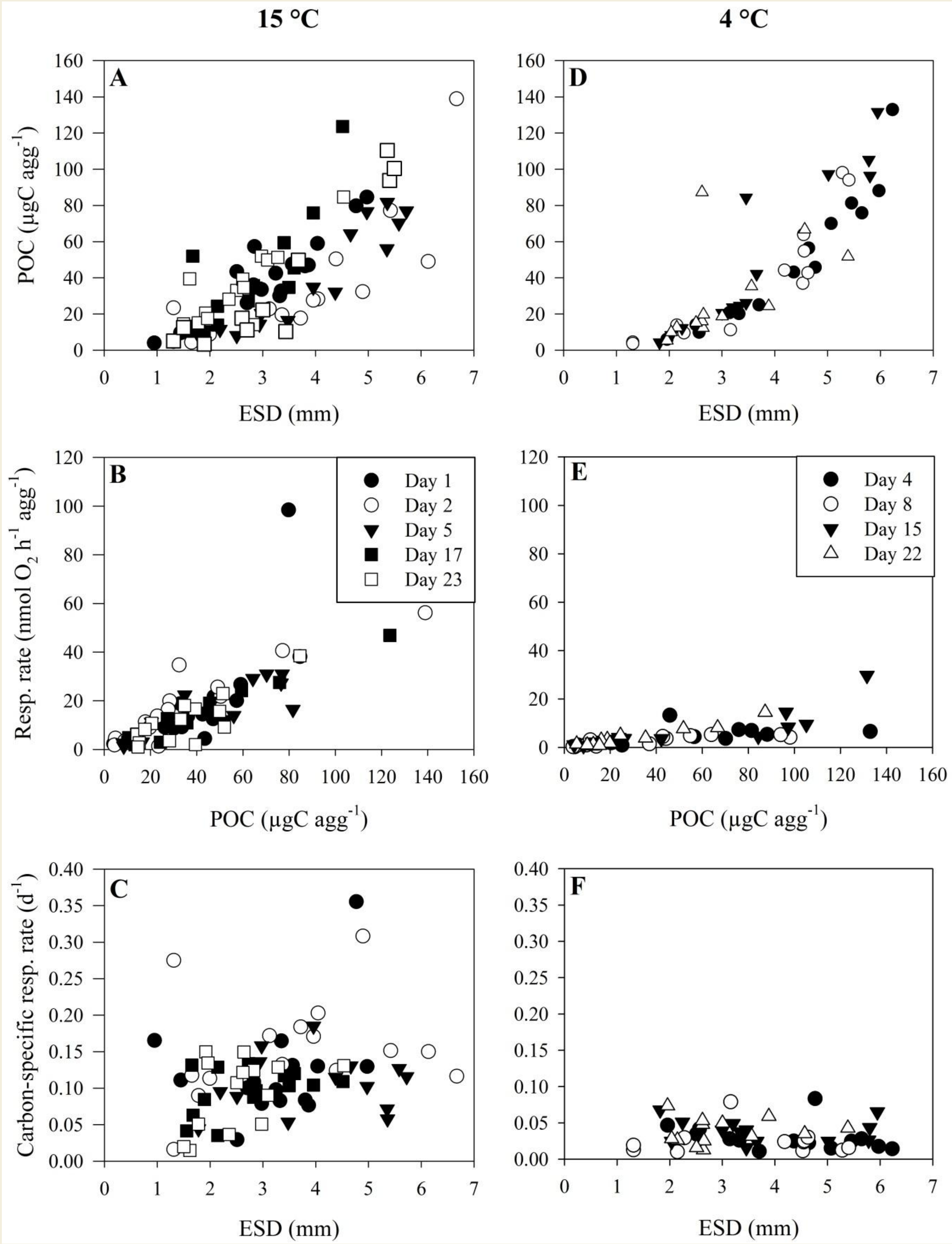


COG FUNCTIONAL CATEGORIES

- **C:** Energy production and conversion
- **D:** Cell cycle control, cell division, chromosome partitioning
- **E:** Amino acid transport and metabolism
- **F:** Nucleotide transport and metabolism
- **G:** Carbohydrate transport and metabolism
- **H:** Coenzyme transport and metabolism
- **I:** Lipid transport and metabolism
- **J:** Translation, ribosomal structure and biogenesis
- **K:** Transcription
- **L:** Replication, recombination and repair
- **M:** Cell wall/membrane/envelope biogenesis
- **N:** Cell motility
- **O:** Posttranslational modification, protein turnover, chaperones
- **P:** Inorganic ion transport and metabolism
- **Q:** Secondary metabolites biosynthesis, transport and catabolism
- **R:** General function prediction only
- **S:** Function unknown
- **T:** Signal transduction mechanisms
- **U:** Intracellular trafficking, secretion, and vesicular transport
- **V:** Defense mechanisms

Ivars-Martinez et al., *ISME Journal*, 2:1194–1212, 2008

Degradation Rates

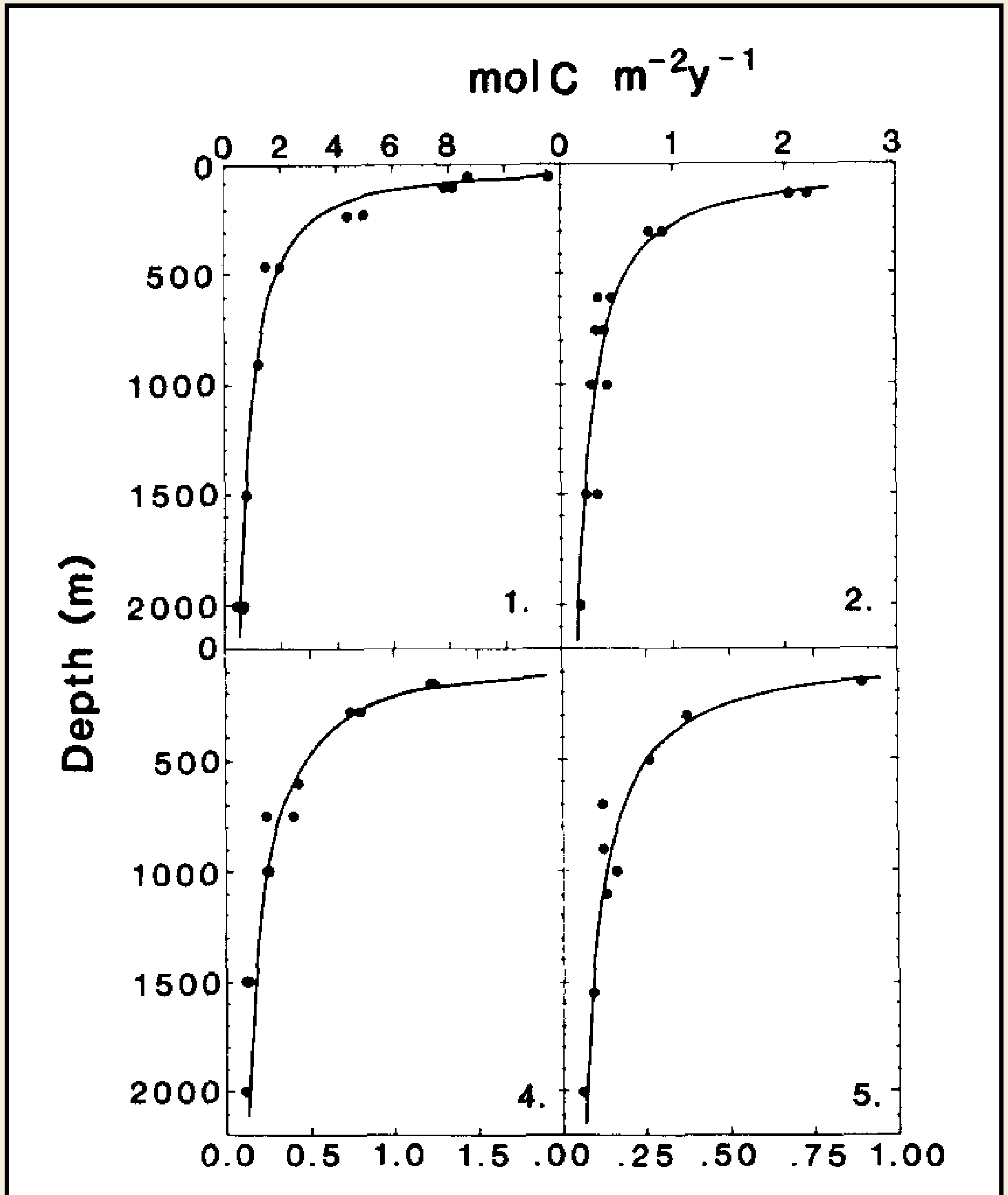


Iversen & Ploug, *Biogeosciences*, 10:4073–4085,2013

C specific degradation rate = 0.12 ± 0.03

C specific degradation rate = 0.03 ± 0.01

Empirical Models

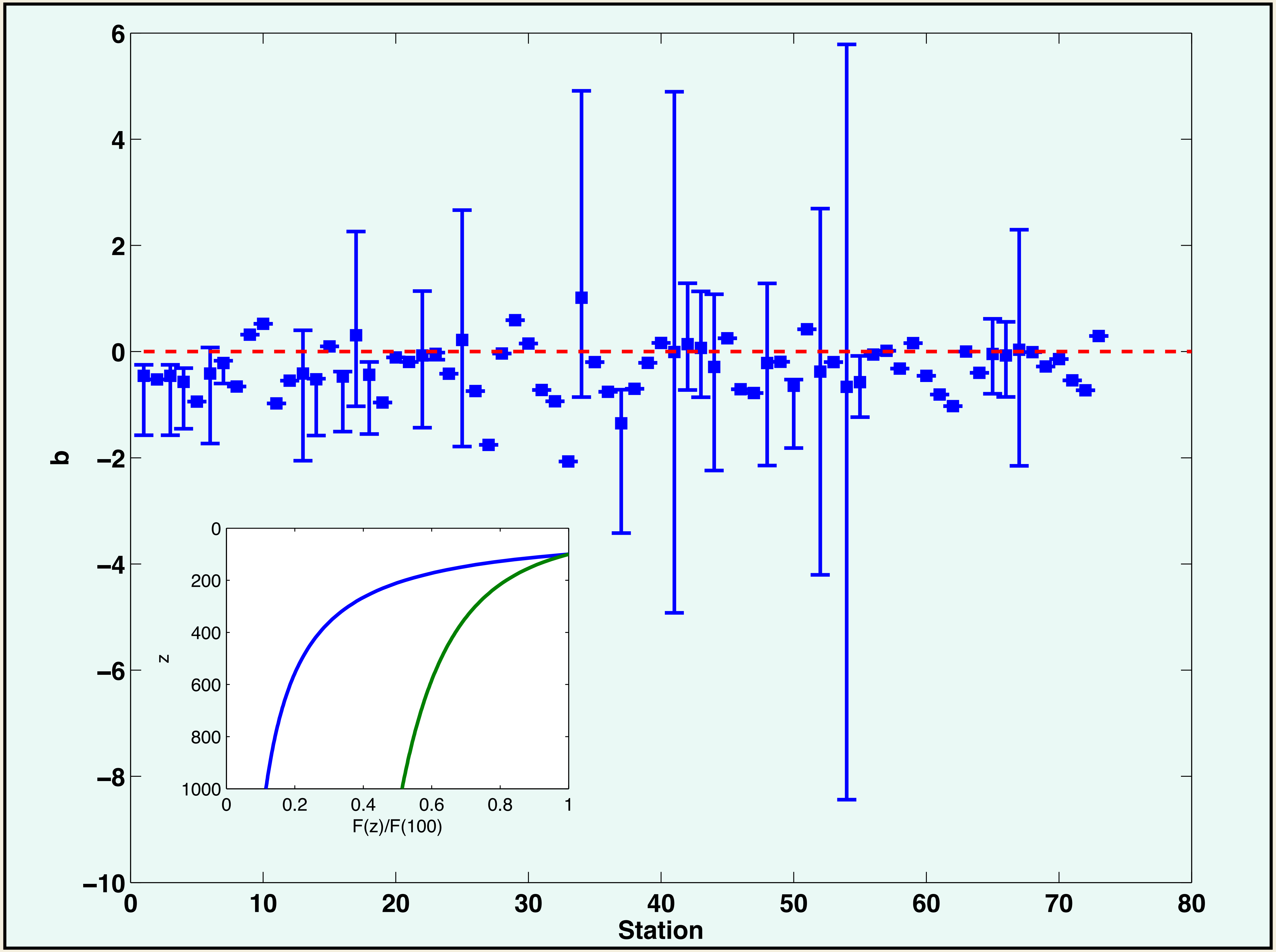


Martin et al., *Deep-Sea Res.*, 1987

$$F(z) = F_{100}\left(\frac{z}{100}\right)^{b}$$

$$b = -0.973 \rightarrow -0.319$$

$$b = -0.858$$

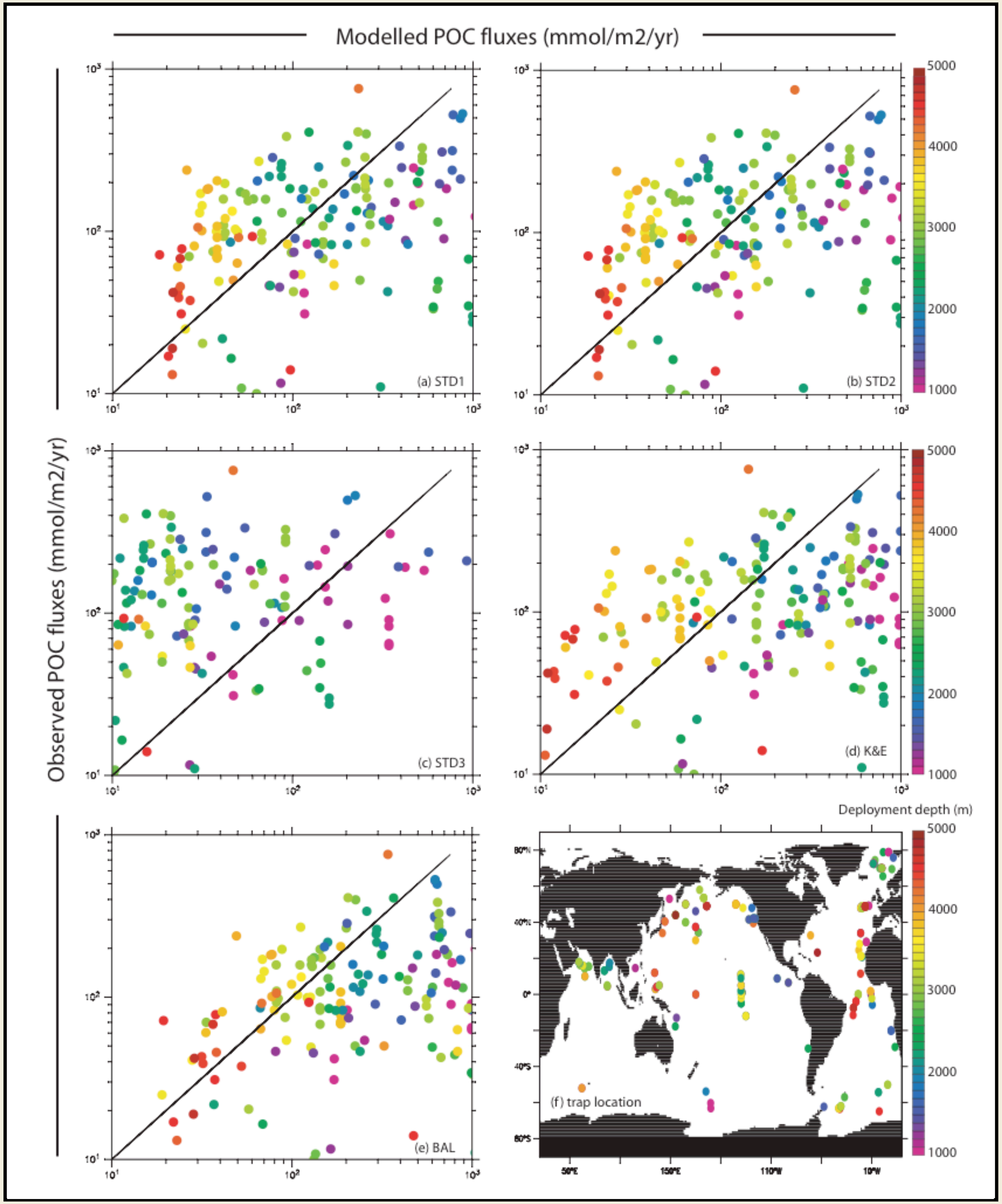


Burd and Passow (unpubublished)

2 size classes, prescribed settling.

2 size classes, prescribed settling, high grazing

Ballast Model

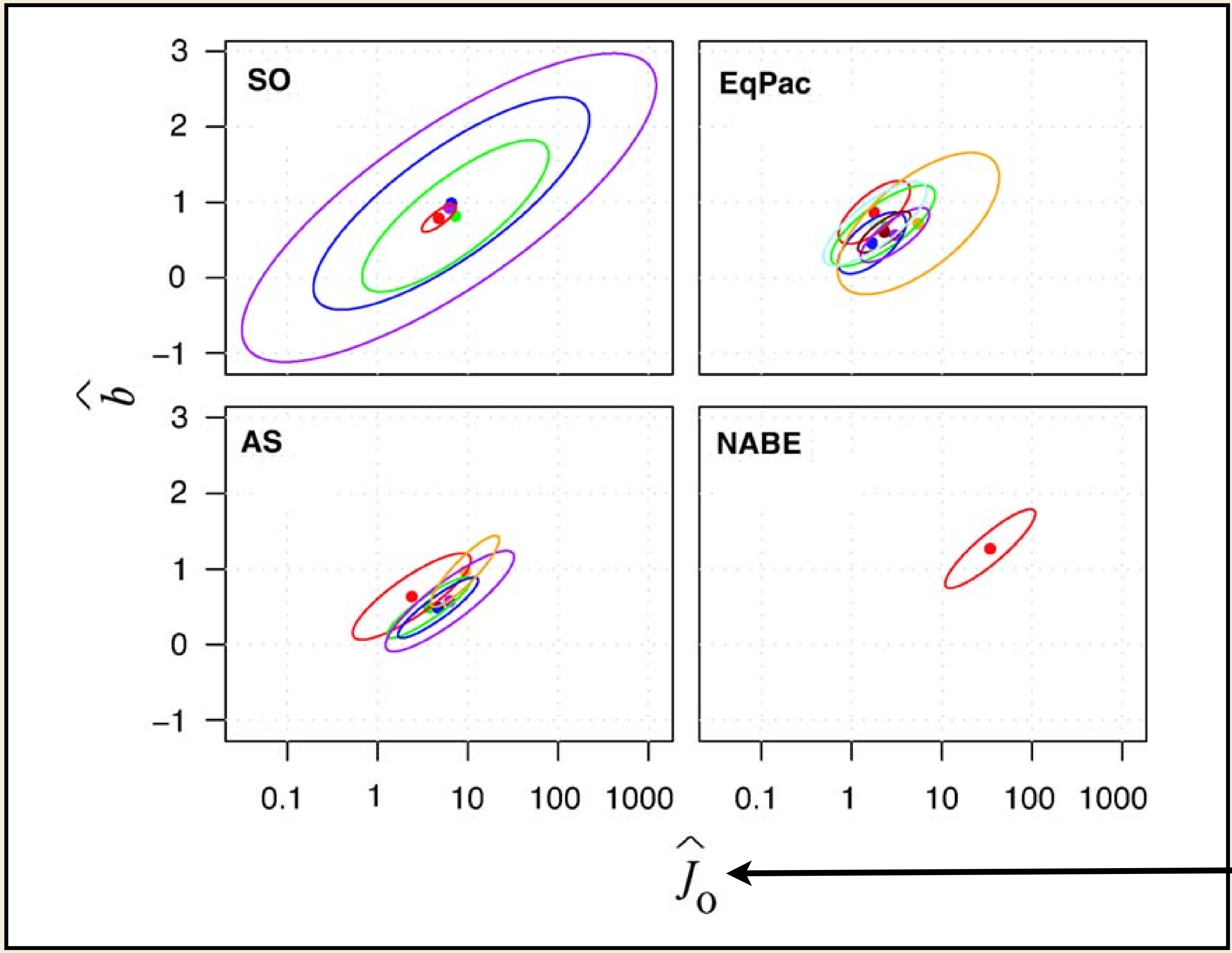


2 size classes, no aggregation, prescribed settling

Simple Spectral Model

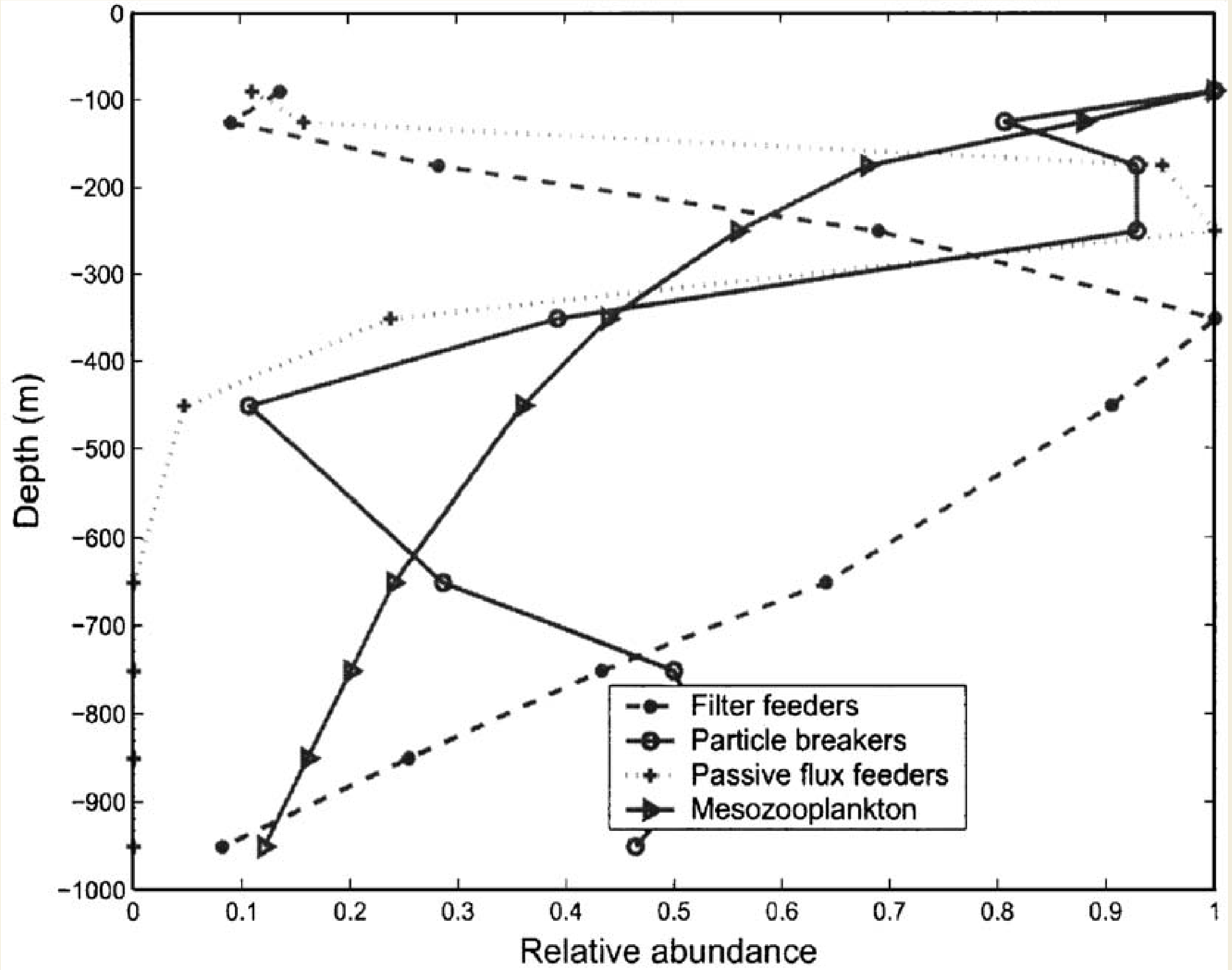
Gehlen et al., *Biogeosciences,* 2006

b-value Uncertainties



Downward POC Flux

Primeau, *Deep-Sea Res. I*, 53:1335-1343, 2006



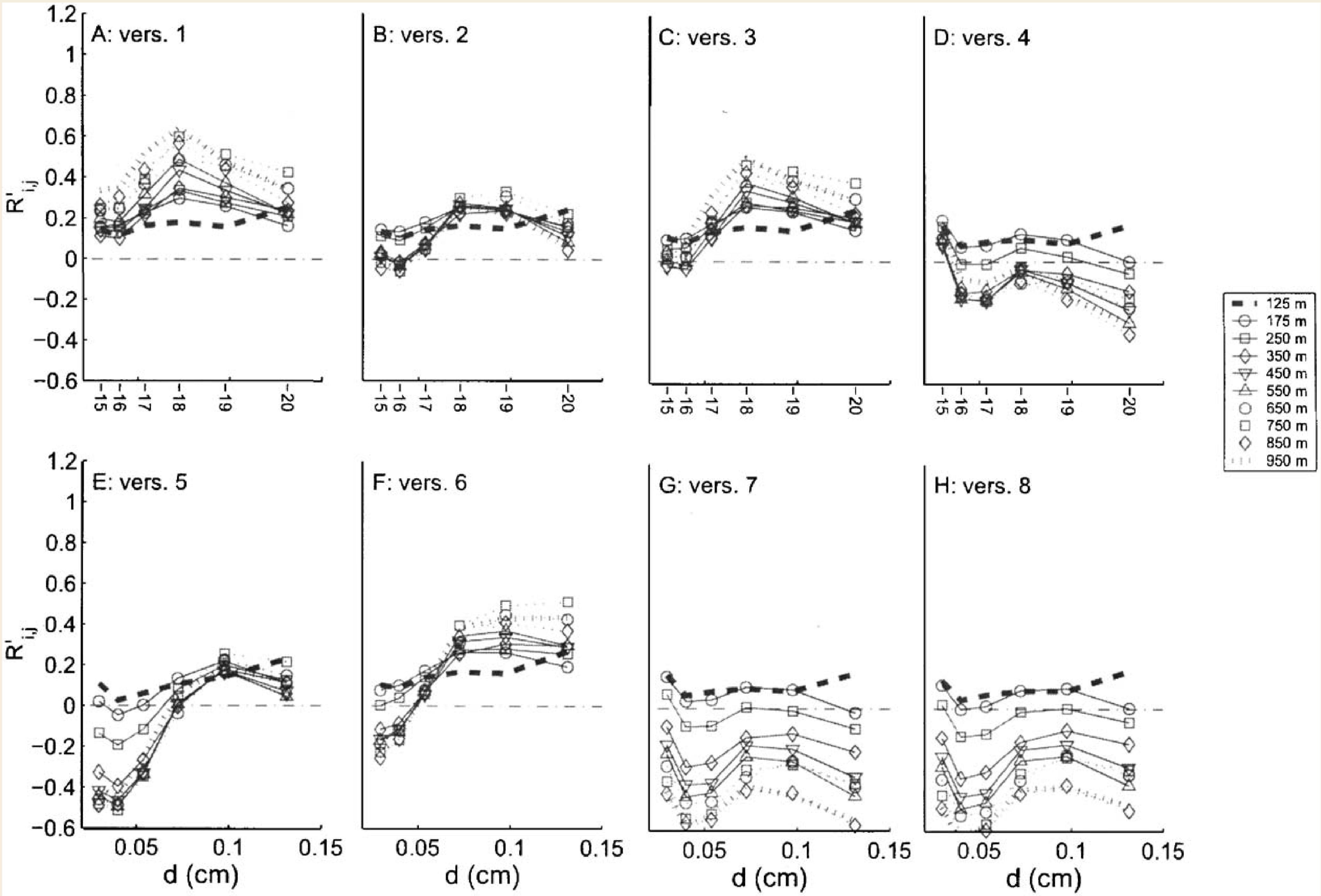
Stemmann et al., *Deep-Sea Res. I*, 51:885–908

Filter feeder scaling factor = 0.307 m^{-3}

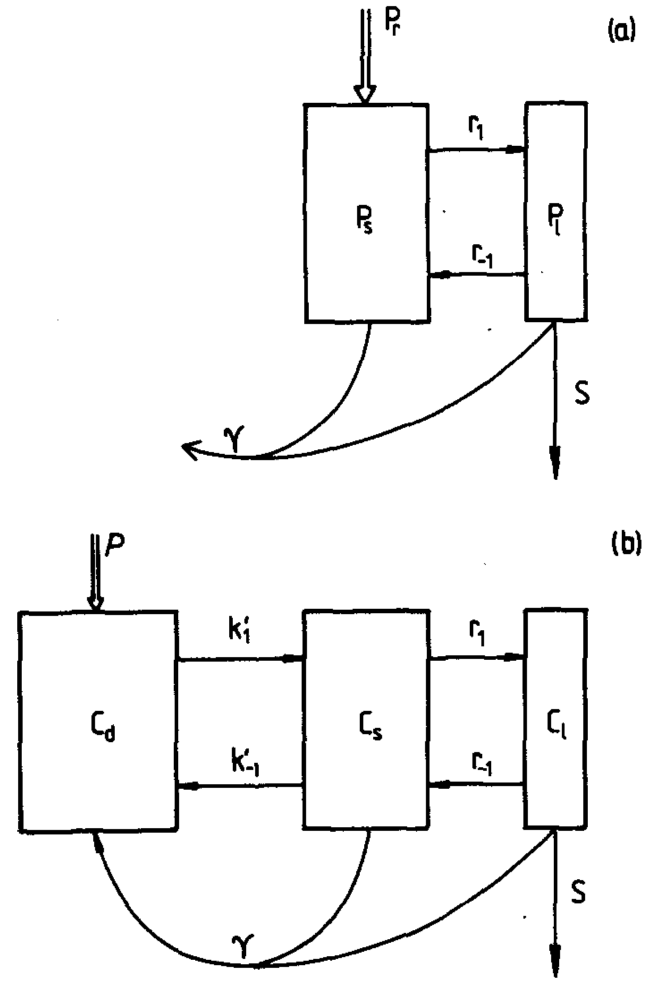
Particle breaker scaling factor = 0.14 m^{-3}

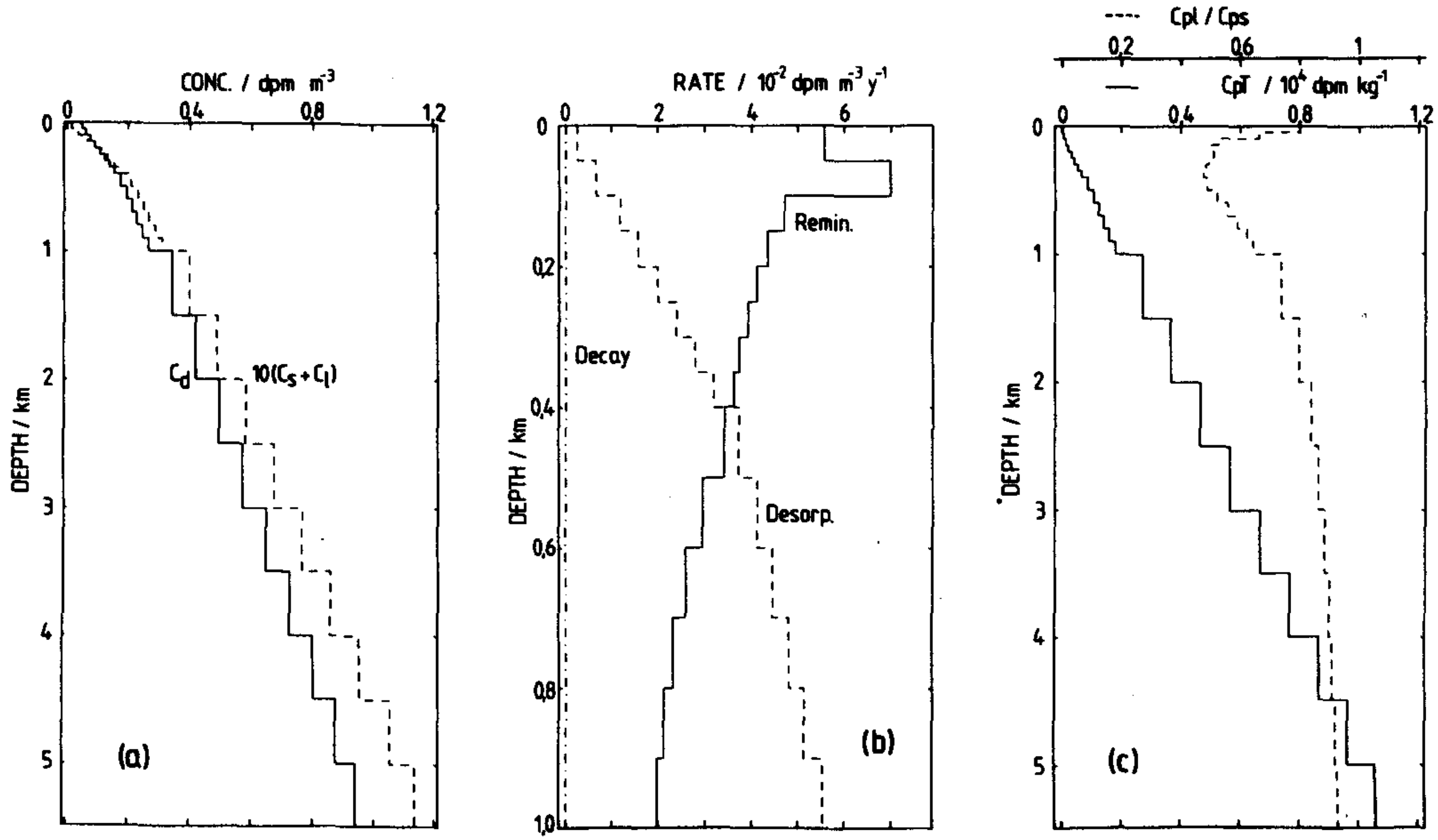
Passive flux feeder scaling factor = 0.063 m^{-3}

Mesozooplankton scaling factor = 250 m^{-3}

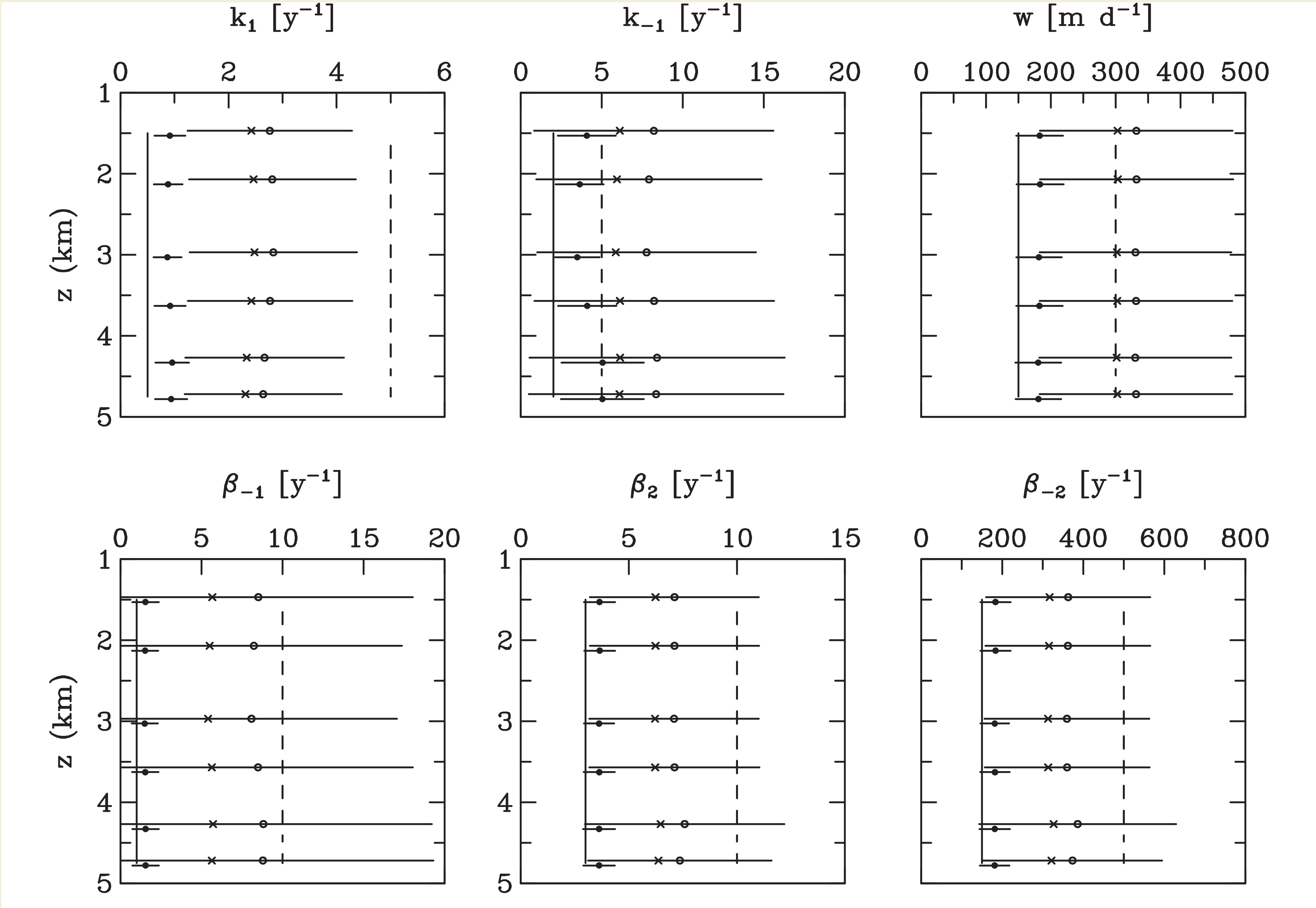


Stemmann et al., *Deep-Sea Res. I*, 51:885–908



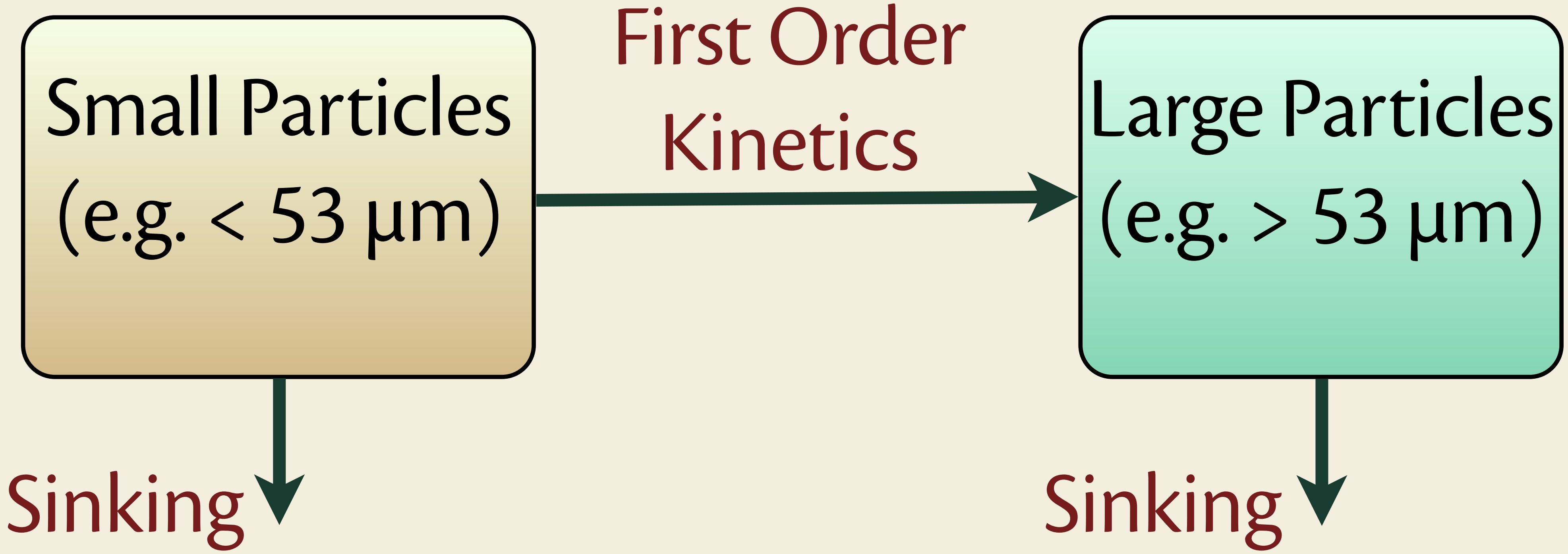


Clegg & Whitfield, *Deep-Sea Res. I, 37:91–120, 1991*



Marchal & Lam, *Geochim. Cosmochim. Acta,* 90:126–148, 2012

Two Size-Classes



$$\frac{dP_S}{dt} = \mu P_S - \tilde{\beta} P_S - \frac{\nu_S}{z} P_S$$

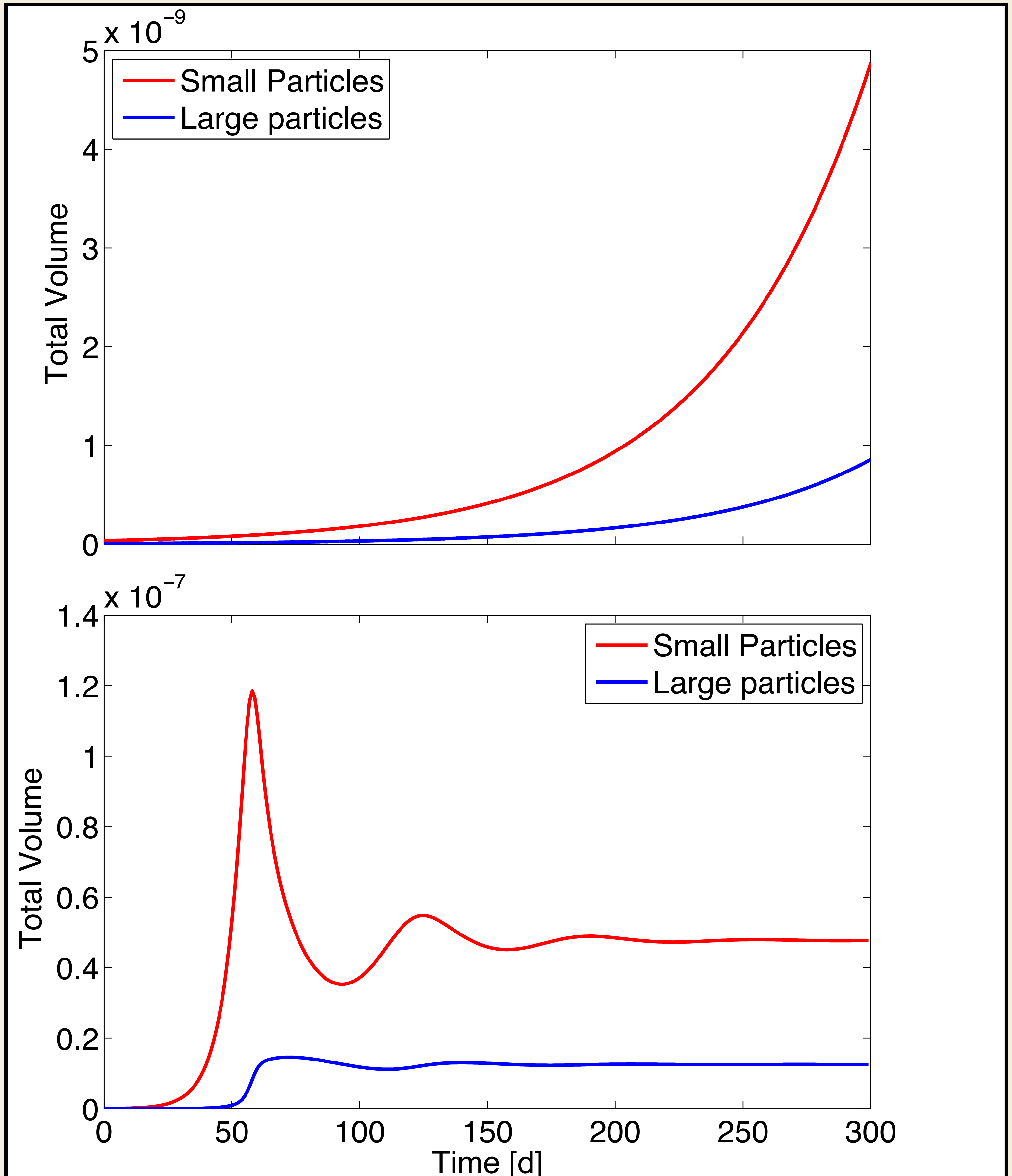
$$\frac{dP_L}{dt} = \tilde{\beta} P_S - \frac{\nu_L}{z} P_L$$

Coagulation Equation

$$
\begin{aligned}
\frac{dn(m,t)}{dt} &= \frac{\alpha}{2}\int_0^m \beta(m_j,\ m-m_j)n(m-m_j,\ t)n(m_j,\ t)\,dm_j \\
&- \alpha n(m,\ t)\int_0^\infty \beta(m,\ m_j)n(m_j,\ t)\,dm_j \\
&- n(m,t)\frac{w_s(m)}{z} + I(m,t)
\end{aligned}
$$

Simple Model Prediction

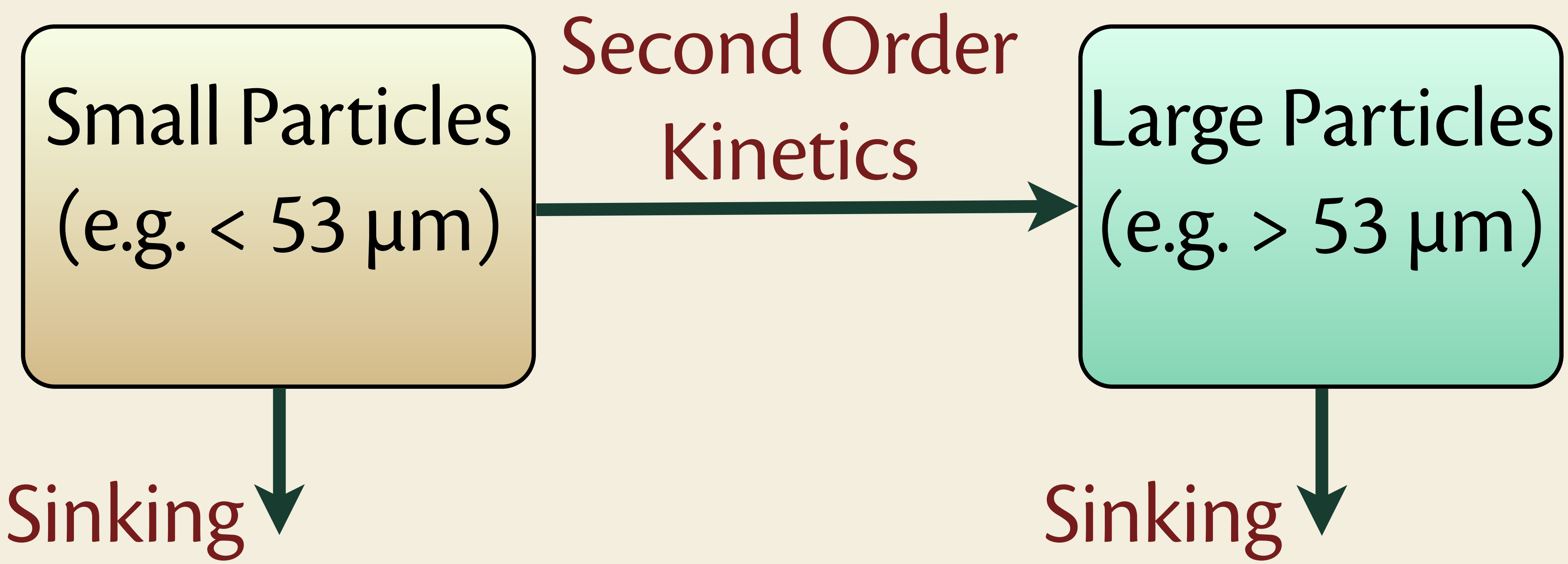
Two size-class model with first order kinetics



Full aggregation model

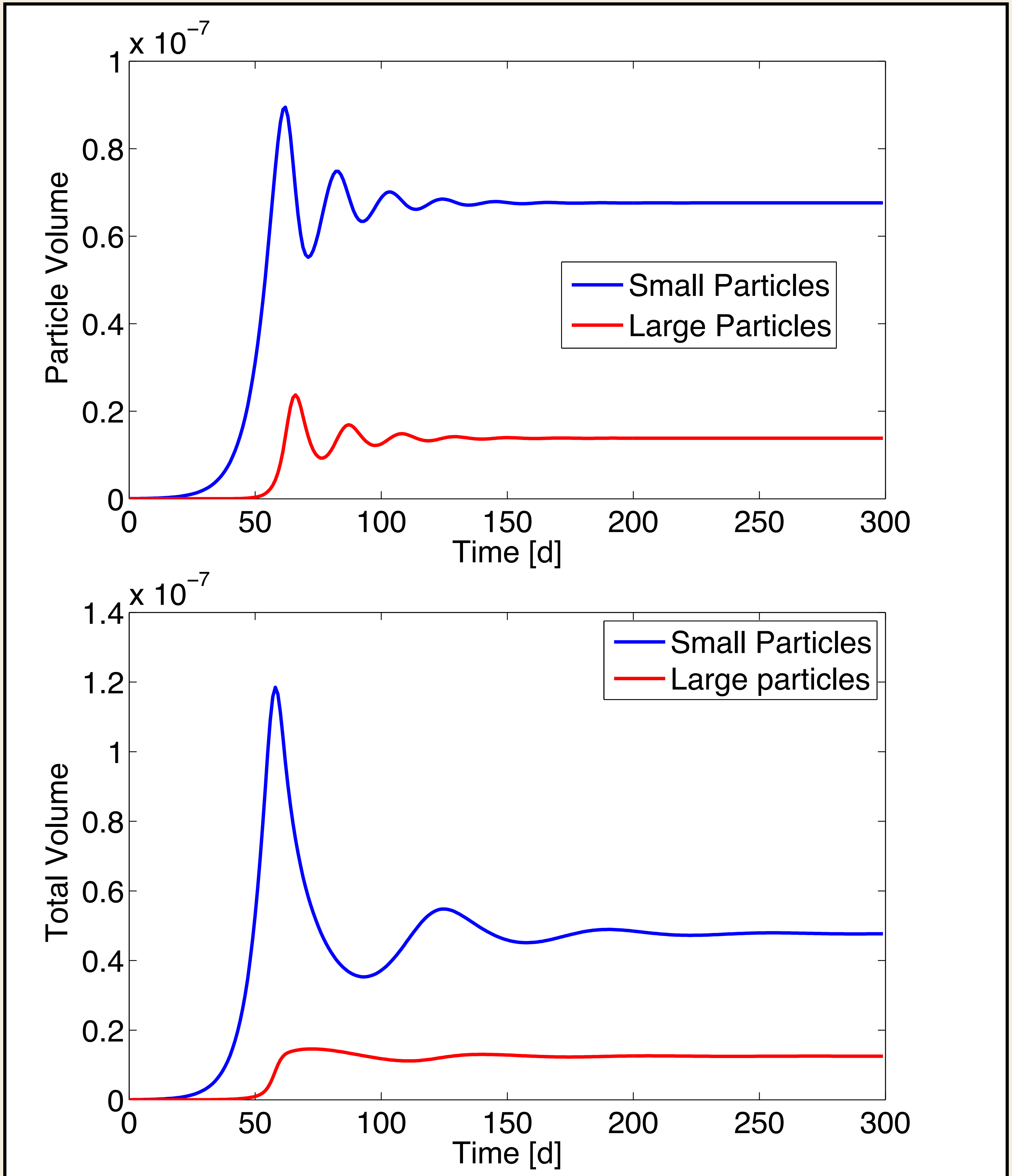
Burd, *J. Geophys, Res.*, 2013

Two Size-Classes



$$\frac{dP_S}{dt} = \mu P_S - \beta_1 P_S^2 - \beta_2 P_S P_L - \frac{\nu_S}{z} P_S$$

$$\frac{dP_L}{dt} = \beta_1 P_S^2 + \beta_2 P_S P_L - \frac{\nu_L}{z} P_L$$

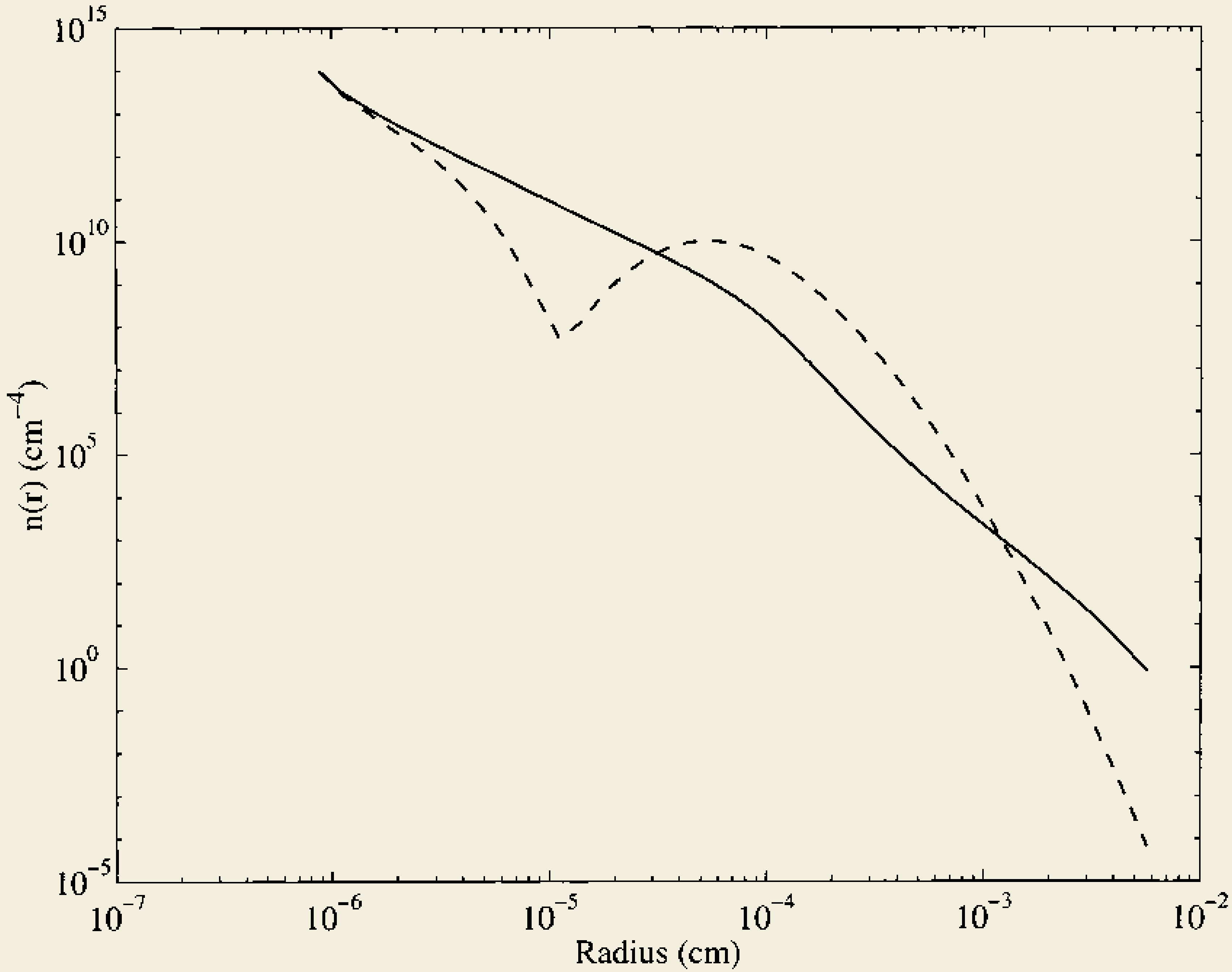


Two size classes, second order aggregation, large/small particle interactions

Full aggregation model

Burd, *J. Geophys, Res.*, 2013

Disaggregation



Burd & Jackson, *Env. Sci. Technol.*, 36:323–327, 2002

Future Work

- **Size resolved aggregation and flux models**
  - *Underway*
- **Better understanding of settling velocities**
- **Better understanding of biological processes**
  - *Particle repackaging, microbial processes*

Questions

- What determines particle sinking velocities?
- Details matter!
- Are there simple relationships between degradation and physical parameters?
- How best to incorporate remineralization into models?