2. Sediments and Biogeochemistry

- Benthic size classes
- Properties of marine sediments
- Sediment biogeochemistry
- Chemical gradients in sediments
  - Biological mediation
  - Physical flow effects

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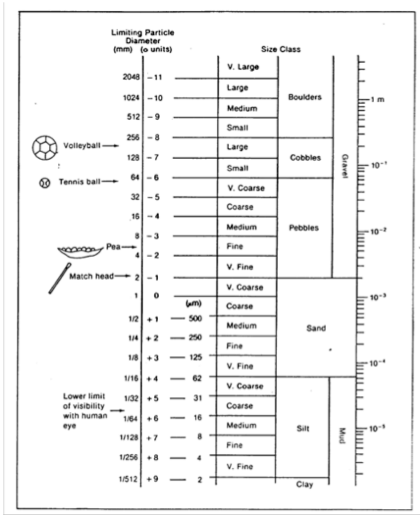
9th April 2010
Reading: Levinton, Chapter 13, "Life in the Mud and Sand"

Benthic Organisms

- **Sizes**
  - **Nanobenthos (microflora/microfauna)**
    - <62μm (shallow-water)
    - <42μm (deep-sea)
  - **Meiofauna**
    - 62μm – 500μm (shallow-water)
    - 42μm – 300μm (deep-sea)
  - **Macrofauna**
    - 500μm – 3cm (shallow-water)
    - 300μm – 3cm (deep-water)
  - **Megafauna**
    - >3cm
    - Large enough to be identified by bottom photos

Marine Sediments



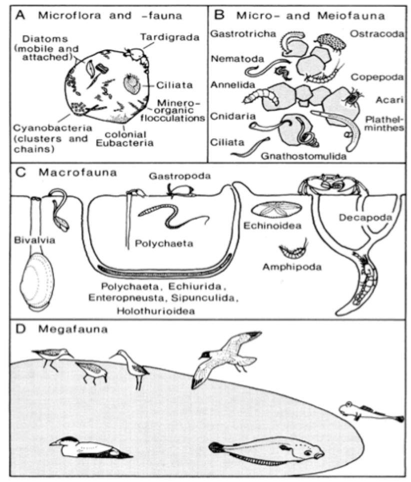


Fig. 2.3 A–D. Representative organisms of tidal flats at the scale of a sand grain (**A**), the interstices of sand (**B**), the sediment (**C**), and the entire shore (**D**)

- Actual sizes not as important as recognizing scale

Marine Sediments

- Rarely consist of just one size fraction
- What factors are important to biology?
- **Surface area**
  - How much space available for colonization
  - ↑ grain size = ↓ available surface area per gram

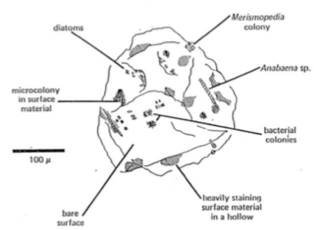


Fig. 4.—Localized distribution of micro-organisms and surface material on an intertidal sand grain (modified from Meadows and Anderson 1966, 1968).

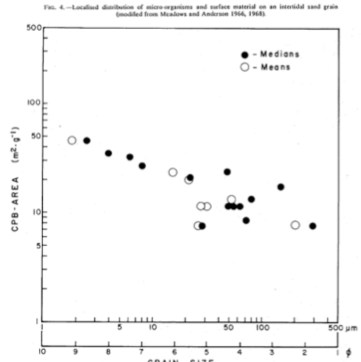


Fig.4. CPB-area versus grain-size medians and means of sediment samples.

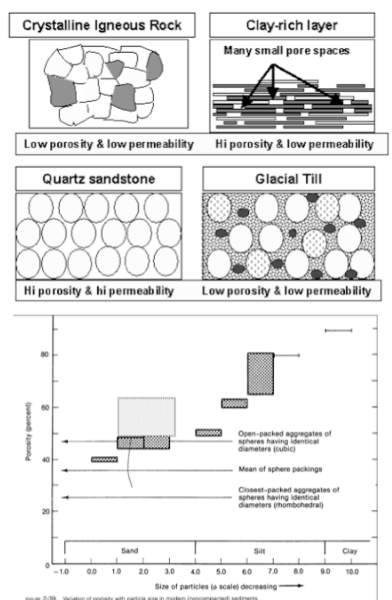
Mayer & Rossi, 1982

Marine Sediments

- **Water**
  - Marine sediments are overlain by seawater of varying depth
  - Water penetrates into sediment, bringing with it chemicals, nutrients & O_2
- Ability of water to penetrate and move is characterized by :-
  - **Porosity**
    - Measure of space within sediment that can be occupied by water
  - **Permeability**
    - Measure of ability of water to flow through sediment

Marine Sediments

- **Porosity**
  - Lowest in sands
  - Highest in clays
- **Permeability**
  - Highest is sands
  - Lowest in clays
- Both factors affect pore water chemistry
  - O_2 is only delivered to marine sediments by –
    - Water flow
    - Burrowers
    - Diffusion
- Diffusion usually slow through sediments
  - Path water takes among sediment grains is long
    - High tortuosity



Friedman et al., 1992

Chemical Gradients

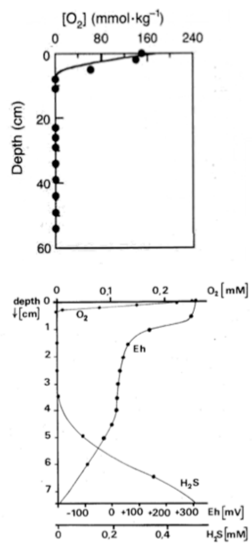


Fig. 7. Comparison of redox potential, oxygen and hydrogen sulphide concentration in a sediment profile. (After Revsbech and Jørgensen 1986)

- Steeper than pelagic
- O_2
  - Sediment
    - Hits 0 <2cm
- H_2S
  - Builds, Anaerobic decomposition
- Redox Potential
  - Aerobes
    - +ve E_h
  - Anaerobes
    - -ve E_h

Giere, 1993

Biogeochemistry

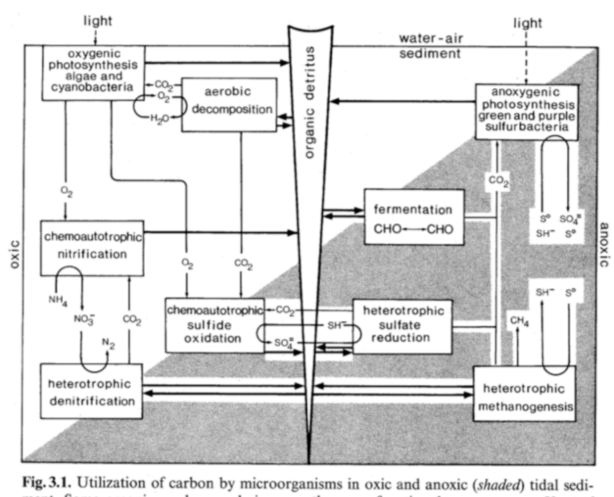


Fig. 3.1. Utilization of carbon by microorganisms in oxic and anoxic (*shaded*) tidal sediment. Some organisms play a role in more than one functional compartment. *Vertical wedge* indicates input of dissolved and particulate detritus from above. *Solid arrows* indicate flow of organic carbon between compartments and the pool of detritus. See text

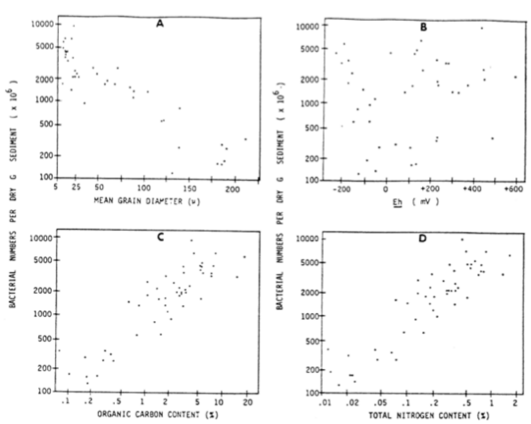
- Many microbial and chemical reactions in sediments
- Aerobic decomposition major reason for ↓O_2
- Amount of organic detritus determines strength of processes

Riese, 1995

Sediment Microbes

- Bacteria - 10^9 cells per gram of sediment
  - Decrease in numbers with depth
    - But even meters down there are bacteria!
  - Bacteria can be ~50% of total non-macrofaunal biomass in upper 1cm
- "Flash Cooking Model"
  - O_2 limited for aerobes
  - Microbes dormant until mixing occurs, then active until nutrients and O_2 is used up

Sediment Microbes

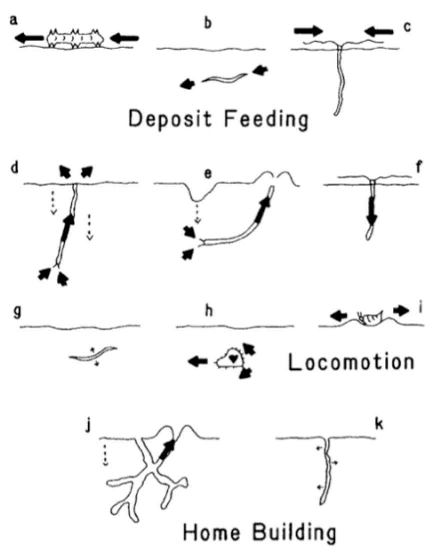


- Factors influencing microbial biomass
  - Grain Size
    - Fine sediments
  - Organic Carbon
    - More organic material = more microbes
  - Redox Potential
    - Mixed – aerobic & anaerobic bacteria
  - Nitrogen
    - Higher N_2, higher microbes

Sediment Microstructure

- Colour has no relationship with amount of oxygen
  - Most marine sediments have low oxygen
- Depth of sulphides
  - Organic content of sediment
  - How aerated sediment is by burrowers
- Often considerable separation between depth of no O_2 and start of H_2S
  - Deep-Sea = little to no H_2S
    - not much organic deposition = low anaerobic decomposition
    - low rates of aerobic activity = higher O_2 at depth

Biological Mediation



- Bioirrigation & Bioturbation
  - Biological mixing of sediments
  - Biological mixing of gradients

Figure 3. Schematic cartoons of the dominant sediment mixing activities discussed in the text. (a) Mobile surface deposit feeder (e.g., some holothuroids and gastropods). (b) Mobile subsurface deposit feeder (e.g., some polychaetes and echinoids). (c) Sessile, surface deposit feeder (e.g., some polychaetes and echiurans). (d) Conveyor-belt or head-down deposit feeder (e.g., maldanid polychaetes and some holothuroids). (e) Funnel-feeding deposit feeder (e.g., arenicolid polychaetes, some holothuroids and enteropneusts). (f) "Reverse conveyor-belt" deposit feeder, an animal that feeds at the surface and defecates at some depth in the sediment (e.g., the polychaete genus *Polycirrus* and some sipunculans). (g) Radial, subsurface burrower (e.g., many polychaetes). (h) Axial burrower that moves by transporting sediment along the axis of its body (e.g., heart urchins and many crustaceans). (i) Surface crawler (e.g., gastropods, many echinoderms, and crustaceans). (j) Burrow excavator (e.g., decapod crustaceans and many other taxa). (k) Tube builder (many taxa). Arrows denote transport direction and relative magnitude.

Wheatcroft et al., 1990

Biological Mediation

- **Deposit feeding** has the greatest effect
  - Eating, moving, pooping....
  - Next lecture......

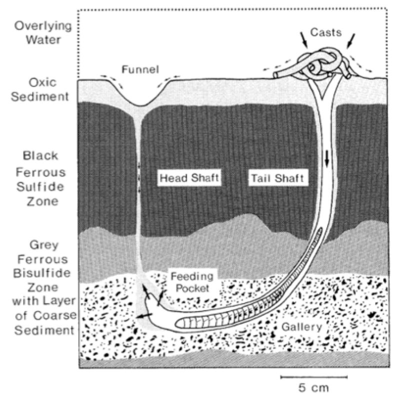


Fig. 11.5. The lugworm *Arenicola marina* in its burrow on a sandy tidal flat of Königshafen, island of Sylt. *Large arrows* indicate flow of overlying water pumped into the burrow. *Small arrows* indicate sediment movement

Reise, 1985

Biological Mediation

- Burrowing
  - Introduce oxygenated water deeper
  - Animals pump water into burrows to aid in digestion

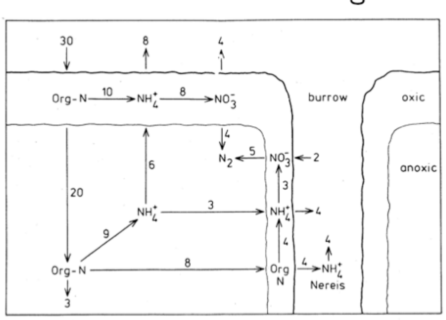
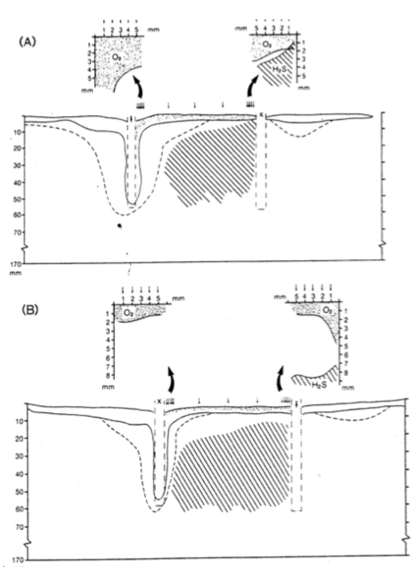


Figure 12.12. A generalized net annual nitrogen budget for sediment from Danish coastal waters ($g\,N\,m^{-2}\,y^{-1}$). The infauna is for simplicity composed of only one species; *Nereis virens*, with a density of 700 individuals/m^2. The rates are based on the knowledge of the yarious processes and are recalculated to the present purpose. The oxic zone at the surface and burrow walls are assumed to be 5 and 1 mm, respectively



Kristensen, 1988

Meyers et al., 1988

Biological Mediation

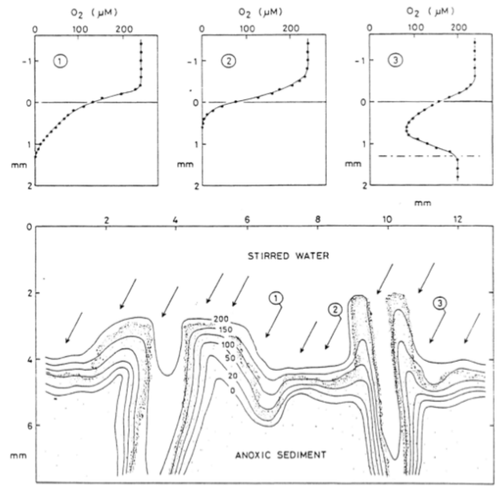


Fig. 7. Vertical section through a sediment surface including two polychaete tubes from Lendrup Lagoon, Limfjorden. The isopleths of oxygen were constructed from twelve microprofiles of which three are shown. Numbers on the isopleths indicate µmol O_2 liter^{-1}. Oxygen from the aerated seawater penetrated through the diffusive boundary layer into a thin, oxic sediment zone which followed the surface topography.

Perez et al., 1999

Jorgensen & Revsbech, 1985

Biological Mediation

- Burrows enhance bacteria and meiofauna
  - Increase surface area of oxygenated sediments
  - Organic matter transport

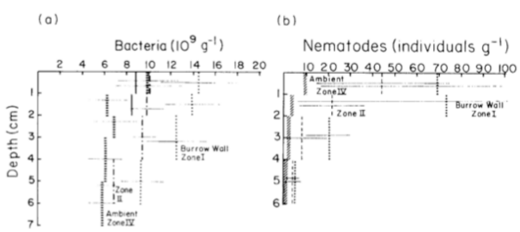


Figure 13.5. Burrows are often sites of enhanced bacteria and meiofaunal populations. (a) Average total numbers of bacteria around five open or vacated and infilled burrows from Nova Scotian Rise, western North Atlantic. Radial zones are ~ 1–1.5 cm successive annuli centered on the burrows at various depths. Ambient is average of numerous subcores taken away from burrows. (b) Average total number of nematodes corresponding to bacteria distributions in (a). (After Aller and Aller, 1986.)

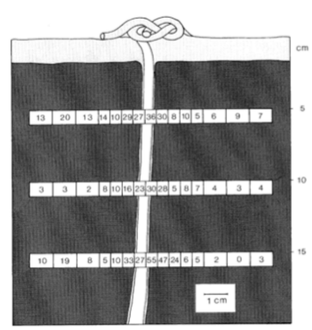


Fig. 11.8. Horizontal distribution of Nematoda in three depth profiles with a tail shaft of a lugworm burrow at the center. *Numbers* represent individuals per 1 cm^3, and are derived from two separate surveys. *Narrow boxes* present sums of two 0.5-cm^3 samples, *wide boxes* average of two 1-cm^3 samples. *Light shading* oxic sediment; *dark shading* anoxic sediment. Sand flat in Königshafen, island of Sylt, October 1978. (Redrawn from Reise and Ax 1979)

Aller, 1988

Reise, 1985

Biological Mediation

- Many species co-living
  - Feed and burrow to different depths
  - No "fixed" rates
- Tracking redistribution of material
  - Tracers
    - Radionucleotides deposited at surface
    - ^{234}Th, ^{210}Pb, Chlorophyll *a*

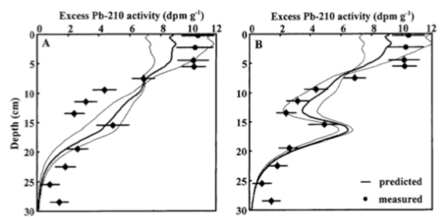


Fig. 6. (A) Predicted and measured profiles of ^{210}Pb without hoeing activity. Solid lines represent the predicted mean and range of excess ^{210}Pb activity, given spatial variability in benthic community structure. Solid circles represent the measured excess ^{210}Pb activity. Horizontal error bars represent total analytical error (±1 SD). (B) Predicted and measured profiles of ^{210}Pb with maldanid polychaetes hoeing sediment to the bottom of their burrows. In this simulation, 40% of sediment ingested by maldanid polychaetes consisted of material collected at the sediment surface by hoeing.

Shull, 2001

Physical Flow

- Not just animals that change sediment properties
  - Natural flow can affect chemical gradients
  - Directly affects where fauna lives
- Consequences for anthropogenic disturbance
  - More anoxic & mixed
  - Less fauna, less burrows
  - Less N_2, O_2 etc.

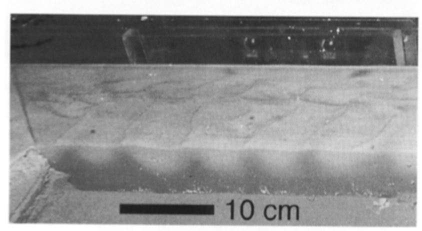


Figure 7.12 Dye washout pattern under a rippled sediment surface in the laboratory flume experiment.

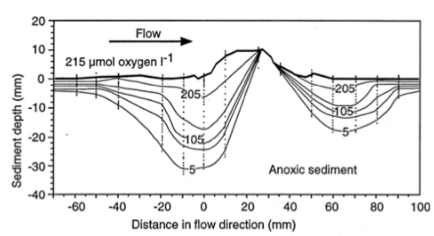


Figure 7.16 O_2 penetration around a small sediment mound, exposed to flow. (Reproduced from Ziebis et al. [1996b], with kind permission of Marine Ecology Progress Series)

Huettel & Webster, 2001

Conclusions

- Properties of sediments have consequences for biological diversity
  - Properties of faunal component can have consequences for sediment composition
- Bacteria make up majority of sediment fauna
- Chemical gradients are steeper in benthos than in pelagic
- Gradients can be affected by fauna & flow
  - Bioirrigation
  - Bioturbation
- Species diversity can be affected by fauna and flow