The impact of microscale changes on fate and behaviour of particle-bound contaminants

Observations and speculation

Sediments and Biodiversity:
bridging the gap between science and policy
7th international SedNet event
6-9 April 2011, Venice, Italy

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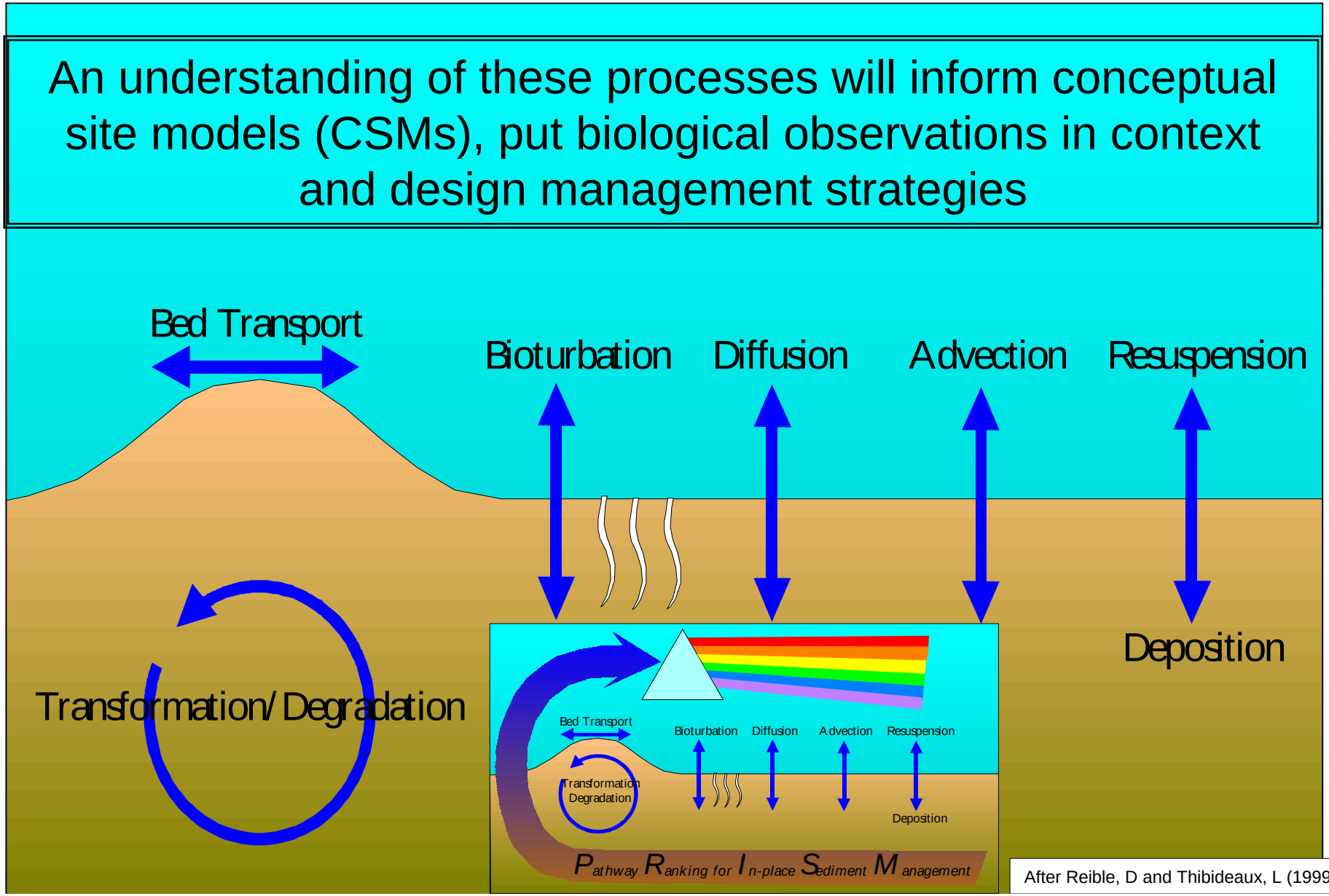
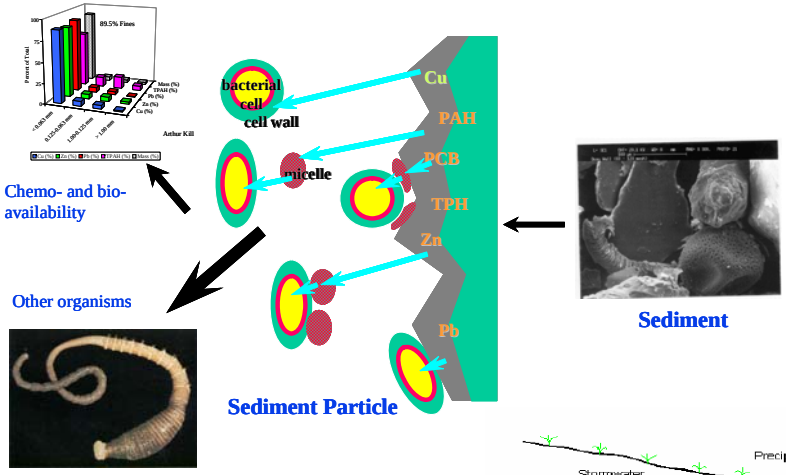
A range of mechanisms affect biophysical status and thus contaminant fate and behavior

An understanding of these processes will inform conceptual site models (CSMs), put biological observations in context and design management strategies



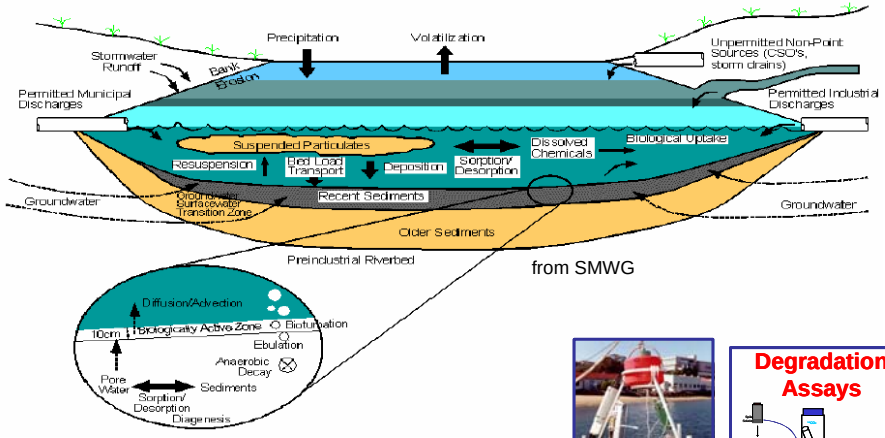
After Reible, D and Thibideaux, L (1999)

…how contaminants interact with sediments…



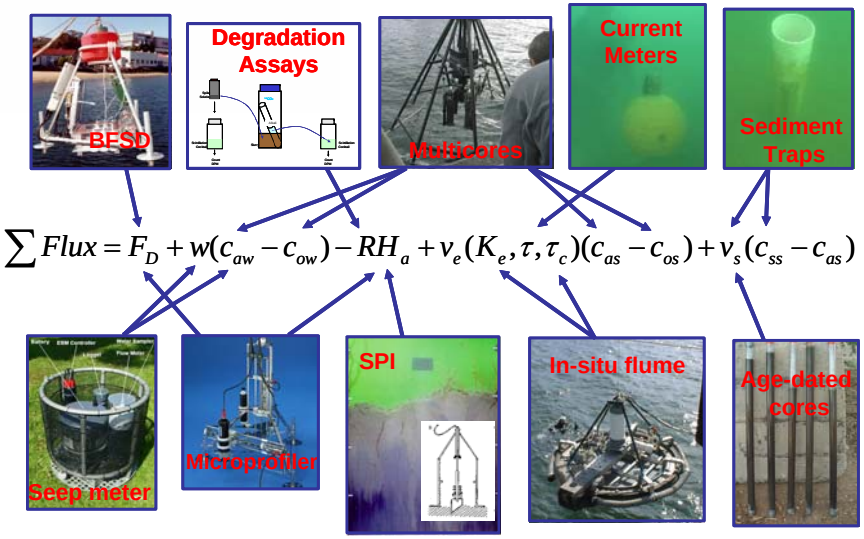
To understand contaminant fate and behaviour at the catchment scale, we need to look at also the micro- and meso-scale interactions to examine…

…how contaminants may move between sediments, water and biota, and…

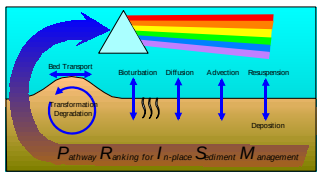


from SMWG

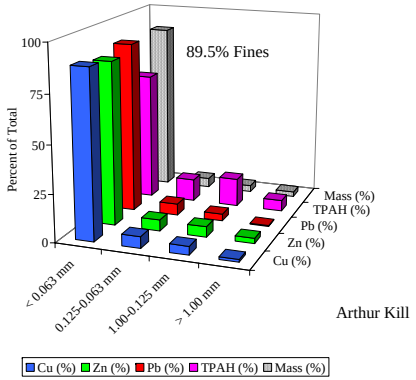
…how contaminants might move over time



$$\sum Flux = F_D + w(c_{aw} - c_{ow}) - RH_a + v_e(K_e, \tau, \tau_c)(c_{as} - c_{os}) + v_s(c_{ss} - c_{as})$$

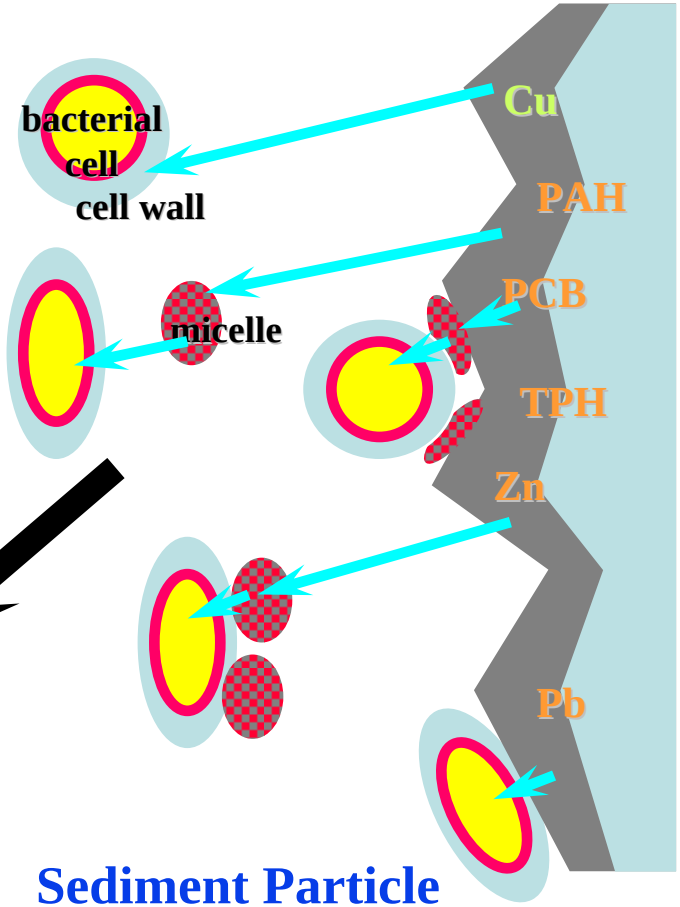


Sediments can bind contaminants in different ways, depending upon sediment characteristics, geochemical conditions and even degree of aging. This can affect contaminant mobility, bioavailability, degradability, fate and risk

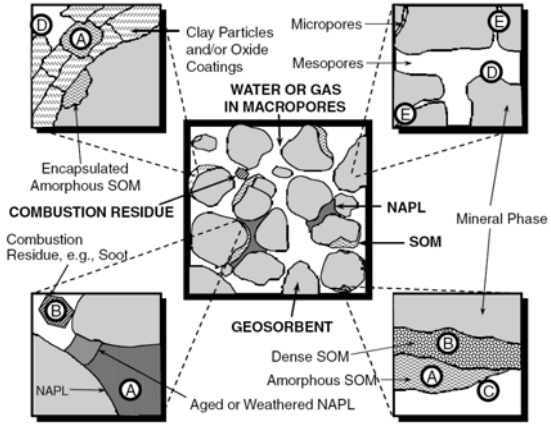


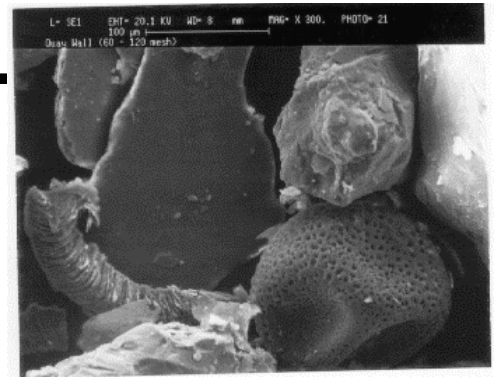
Chemo- and bio-availability

Other organisms



Sediment Particle





Sediment

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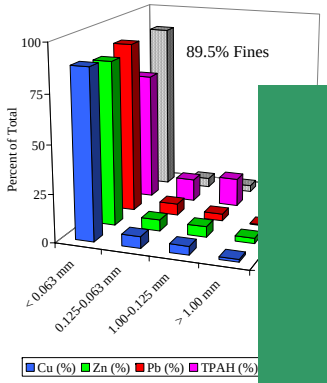
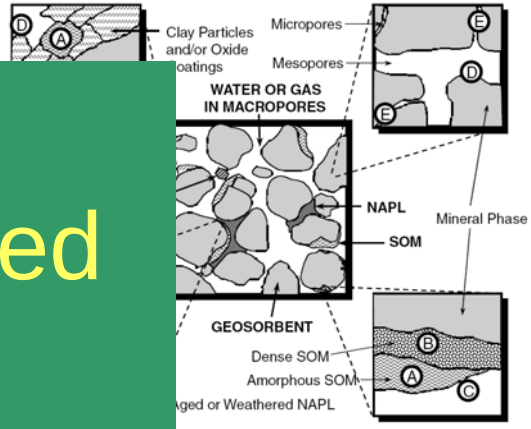
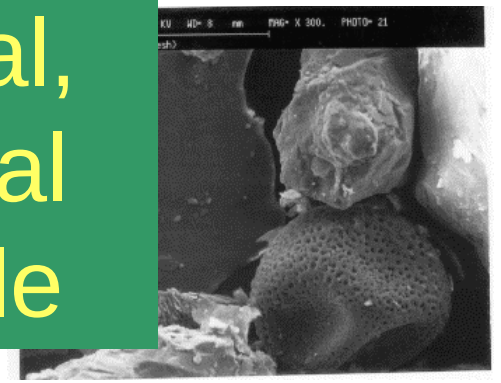


Chemo- and bio-availability

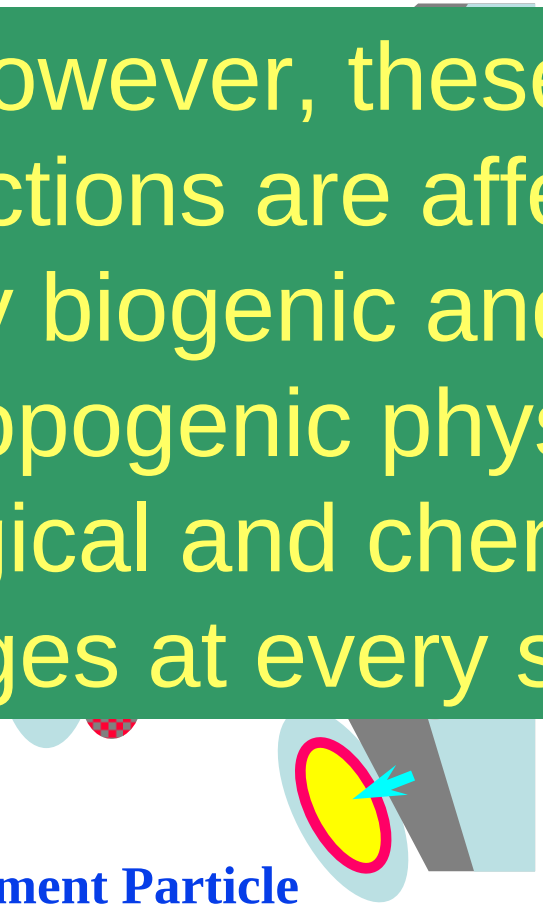




Sediment

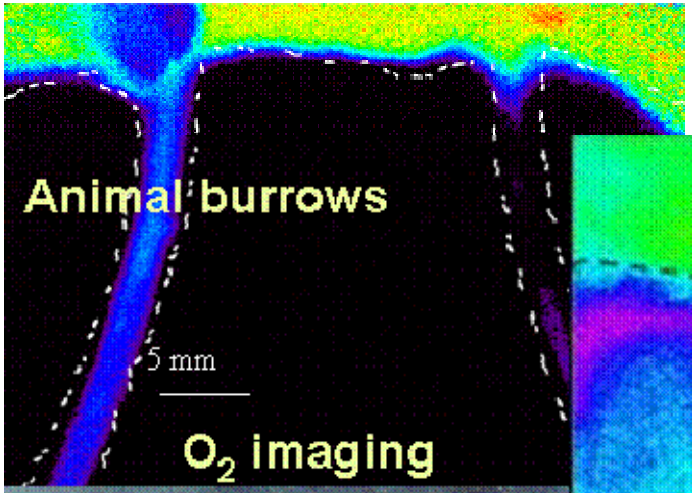
However, these interactions are affected by biogenic and anthropogenic physical, biological and chemical changes at every scale

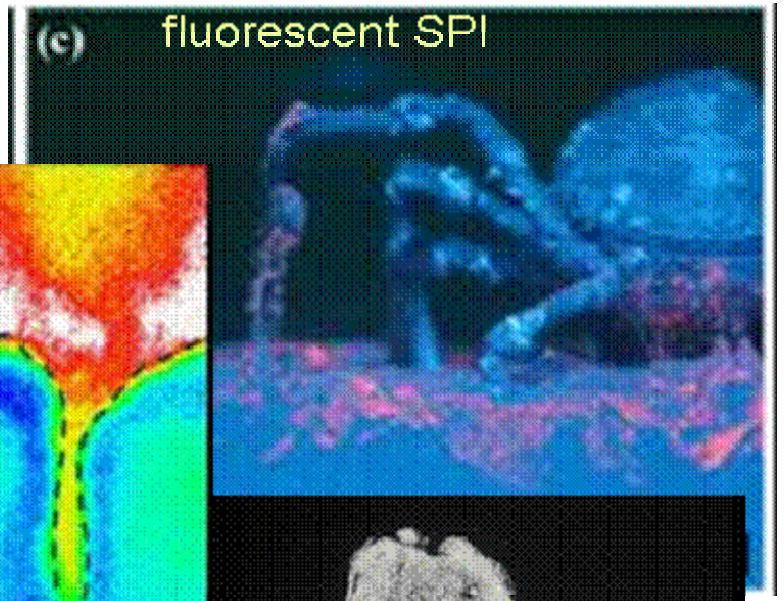
Other organisms

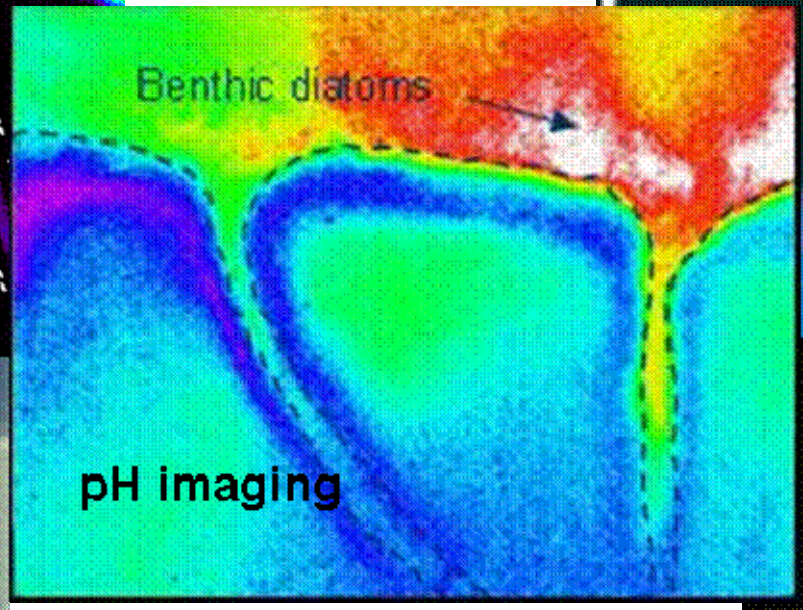


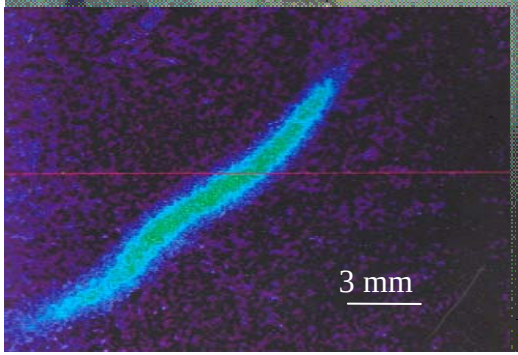
Sediment Particle

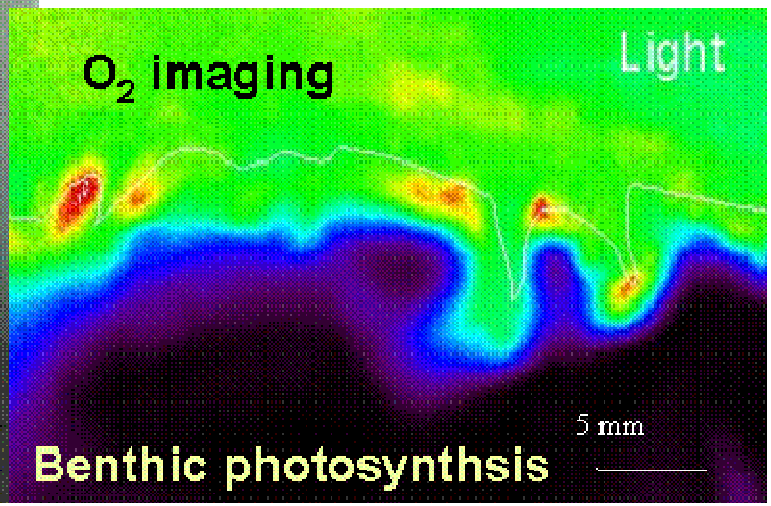
Micro-scale biogenic processes control the biophysical conditions that affect ecosystem function and contaminant fate and behaviour



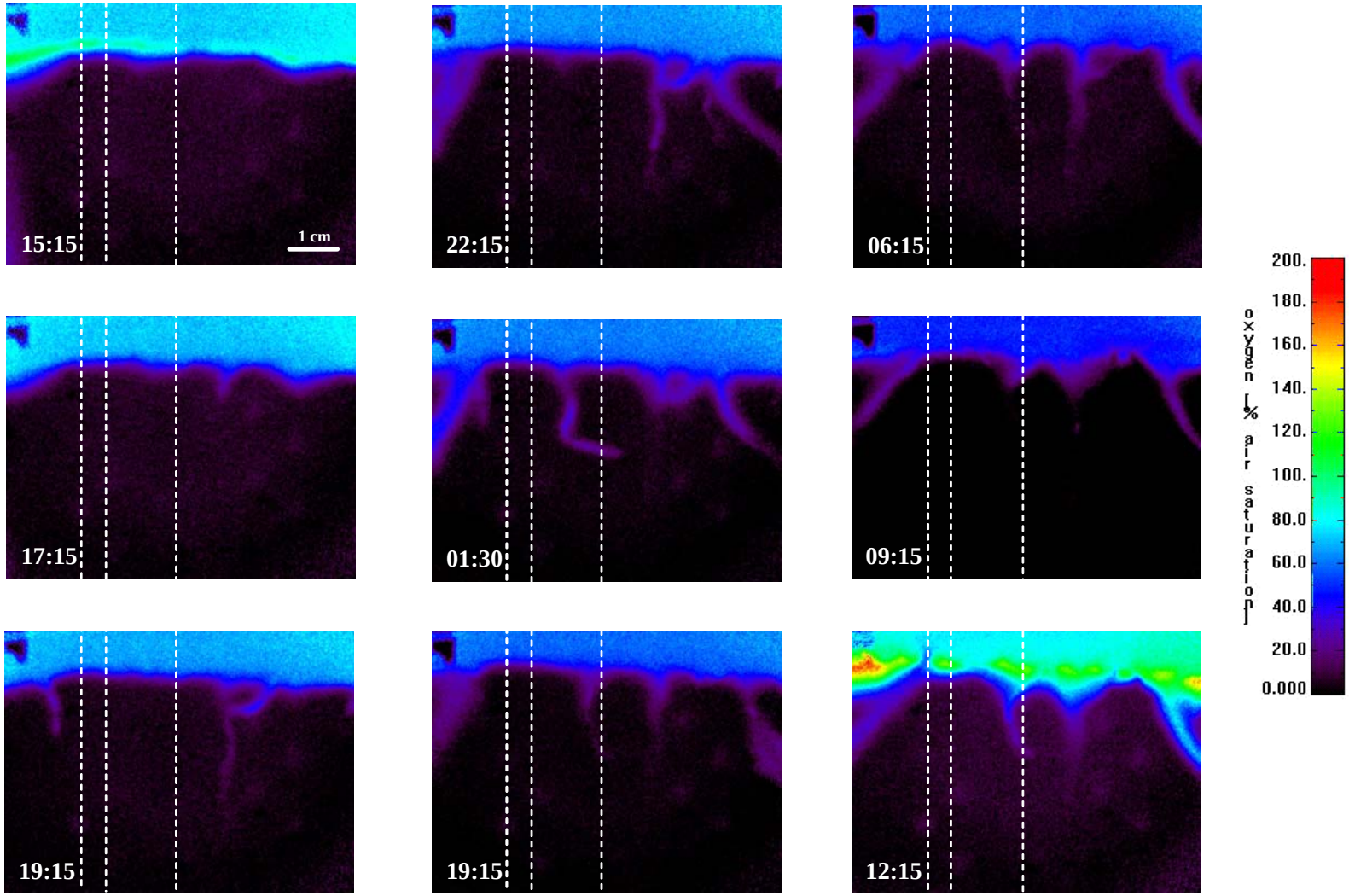








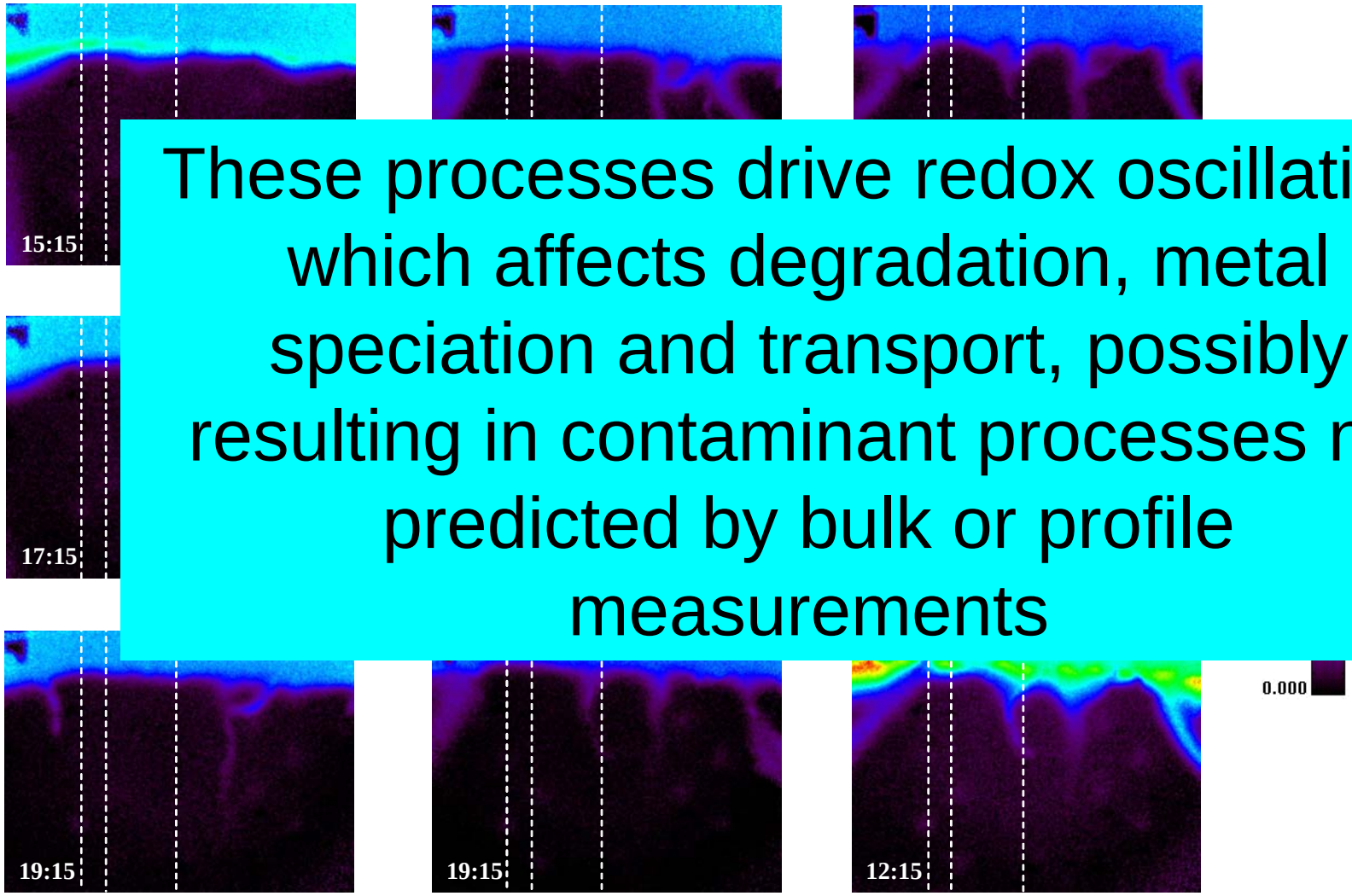
Time-lapse 2-D images of O_2 distribution from planar Optodes – over a 24 hour period, much of this "reduced" sediment is oxic



How does this affect chemical fluxes? Should we treat sediments as reduced or oxic?

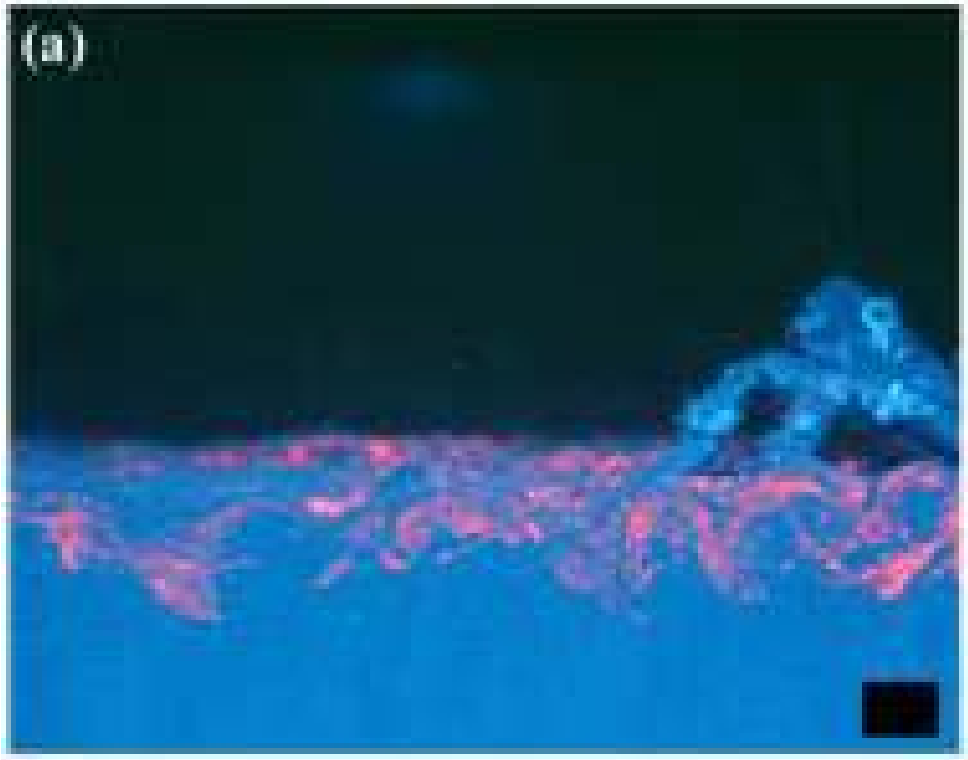
UCOP

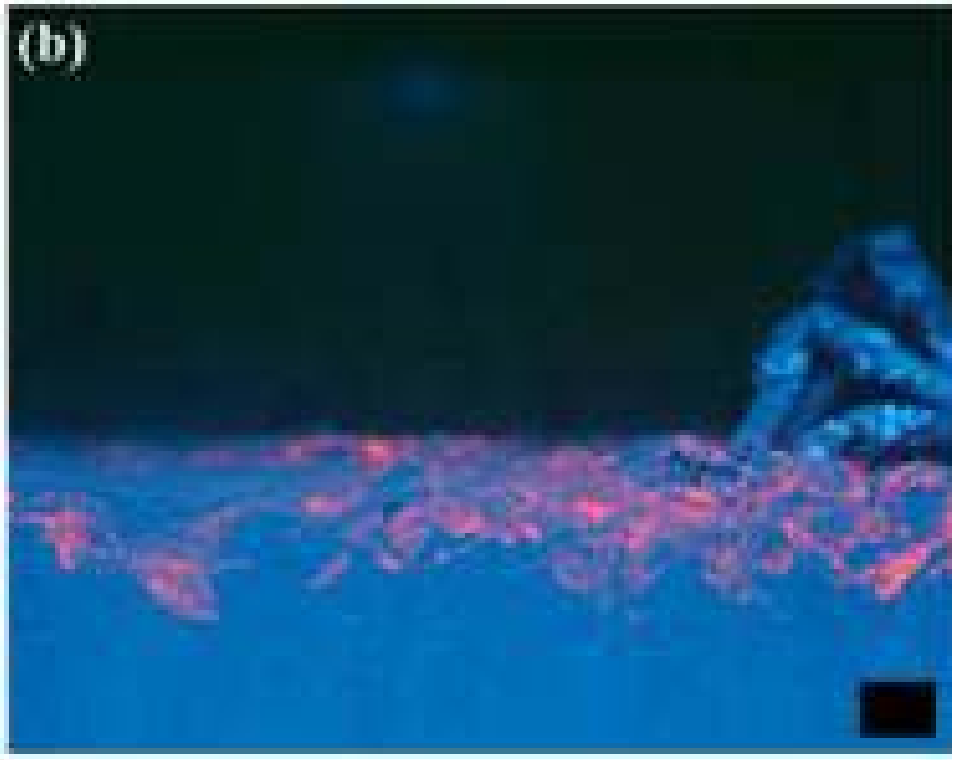
Time-lapse 2-D images of O_2 distribution from planar Optodes – over a 24 hour period, much of this "reduced" sediment is oxic



These processes drive redox oscillation, which affects degradation, metal speciation and transport, possibly resulting in contaminant processes not predicted by bulk or profile measurements

How does this affect chemical fluxes? Should we treat sediments as reduced or oxic?





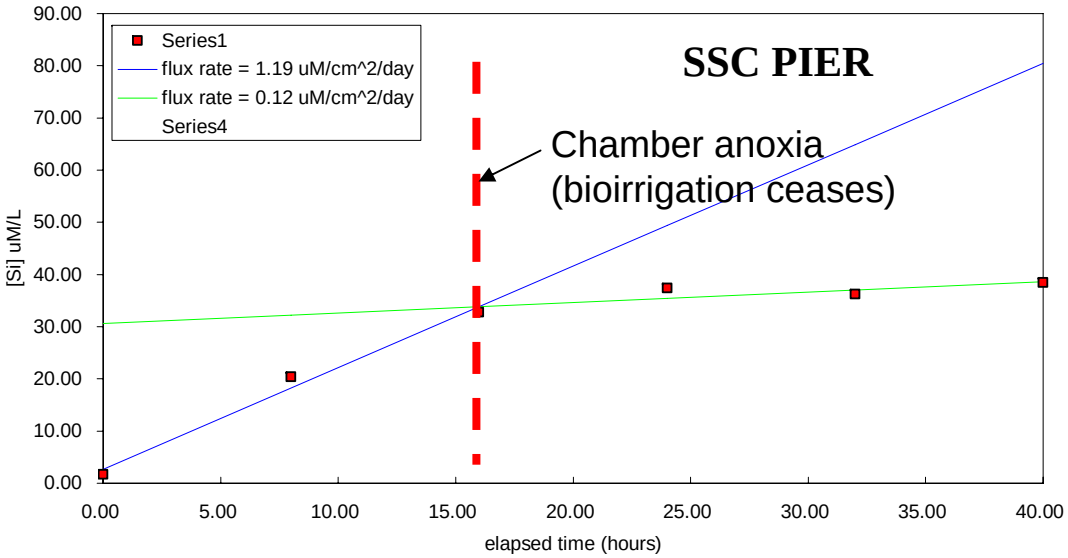
Sediment Profile Imaging (SPI) + fluorescent imaging:
Crab bioturbation relocates fluorescently labelled sediment particles

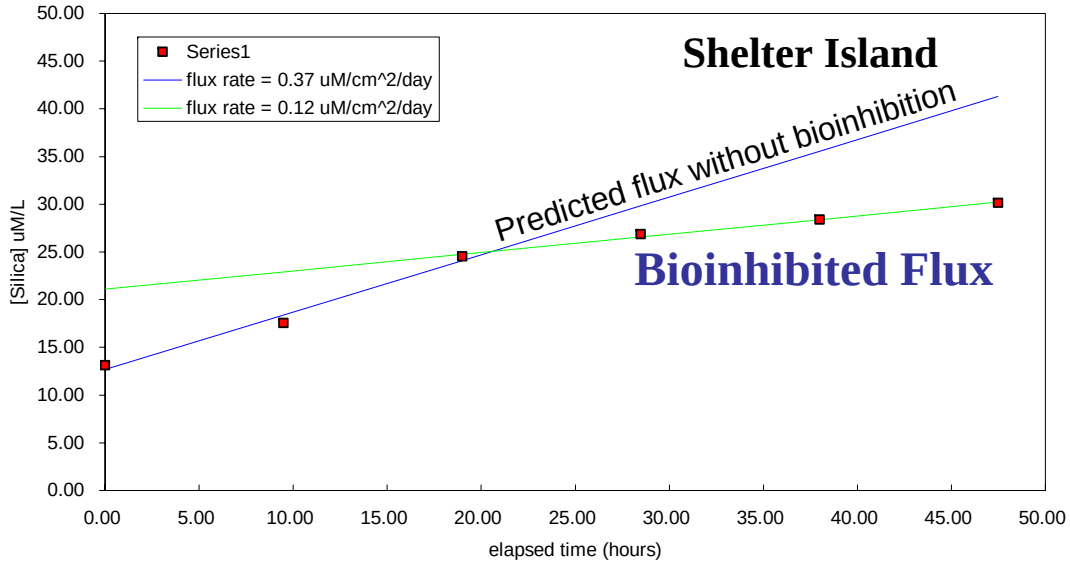
Sometimes it is not the benthic infauna that drive transport

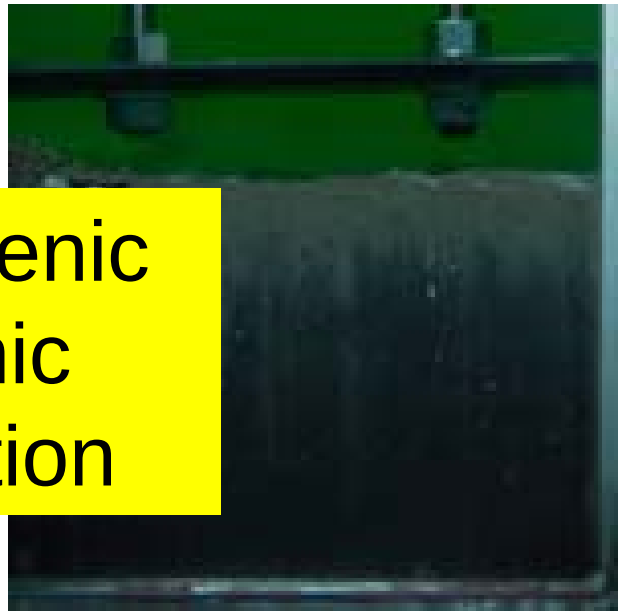
Bioirrigation v Diffusion

- Bioirrigation can be a major component of fluxes (60-90% of overall diffusive flux)
- This can drive contaminant fluxes much higher than are predicted by chemical gradients
- This process rarely measured or modeled

Si fluxes in benthic Chambers; chambers allowed to go anoxic





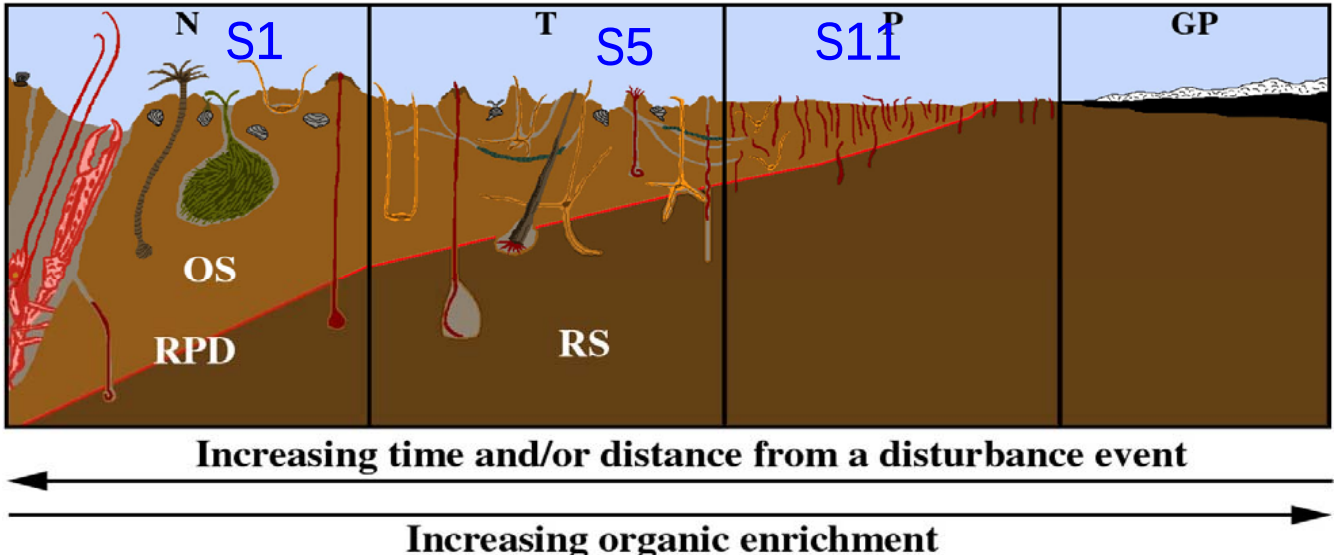


A range of anthropogenic impacts drive benthic community composition

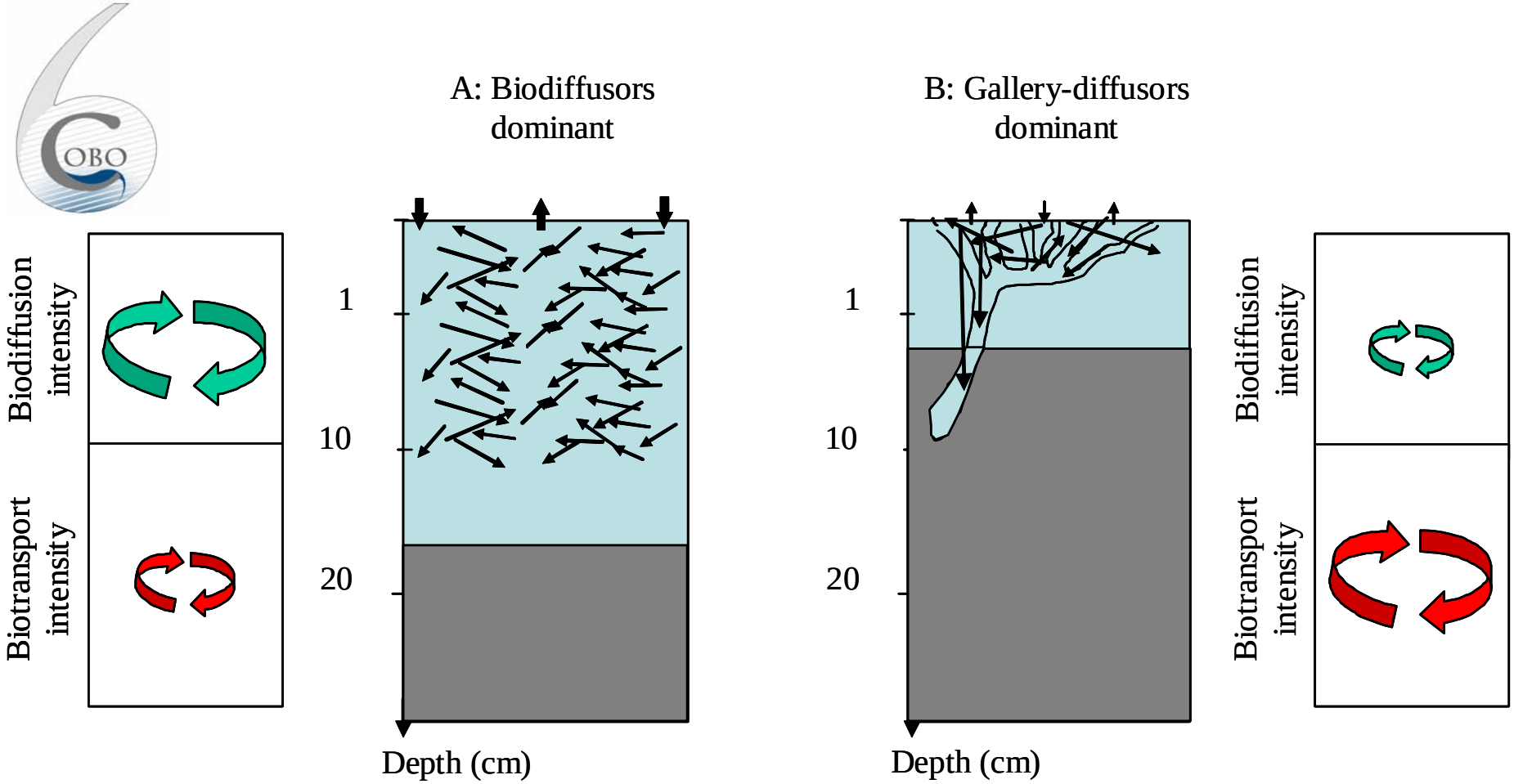
Clean;
Deep bioturbation,
large BMD

Some inputs
Shallower bioturbation,
BMD reduced,

Heavily impacted
BMD reduced,
bioturbation minimal



Schematic diagram showing two types of sediment reworking.



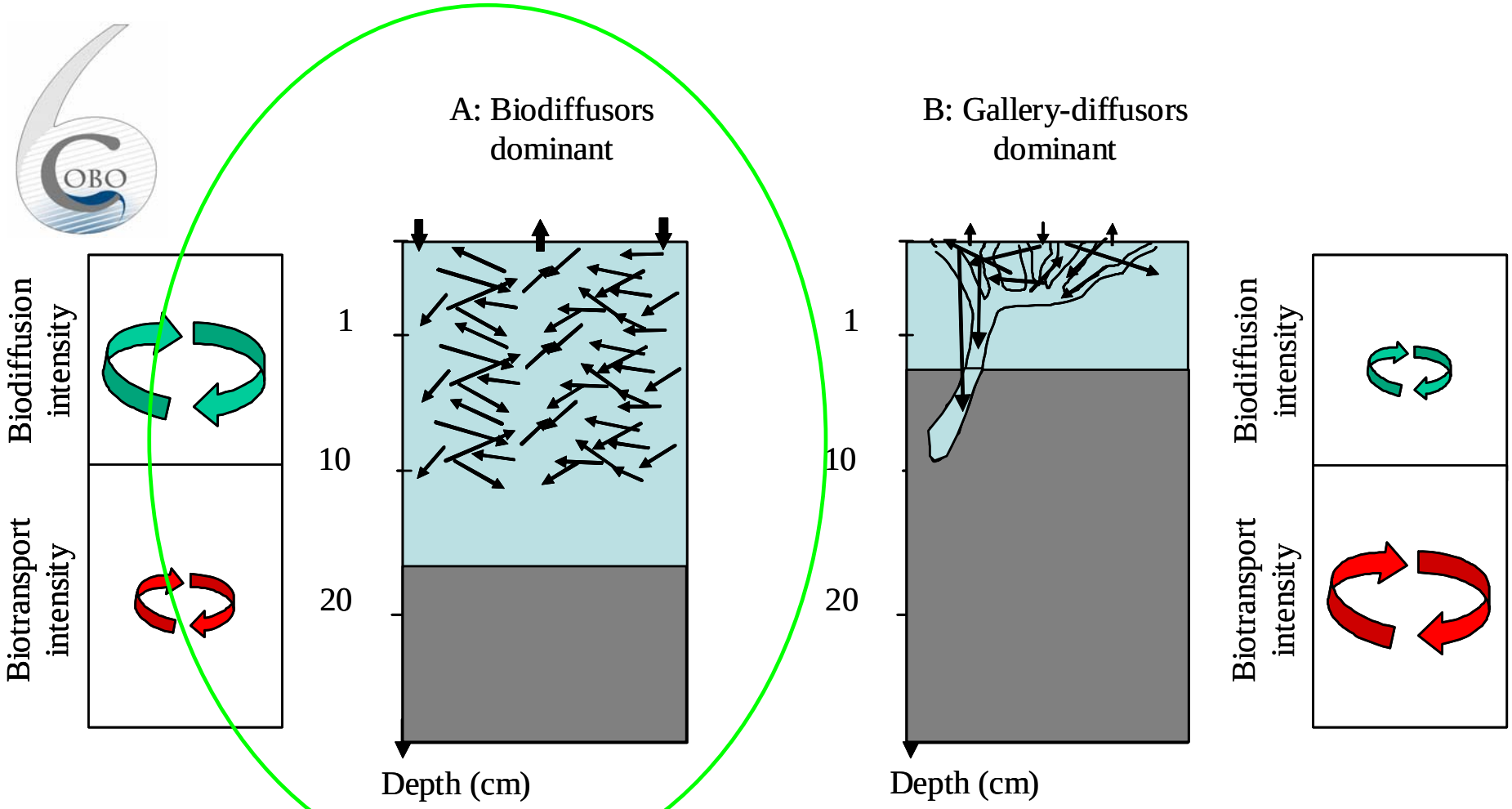
Bioturbation type: Biodiffusion
→High biodiffusion coefficient and low biotransport coefficient

Bioturbation type: Gallery diffusion
→ Lower biodiffusion coefficient and higher biotransport coefficient

From Franck Gilbert

www.cobo.org.uk

Type A enhances beneficial microbial activity



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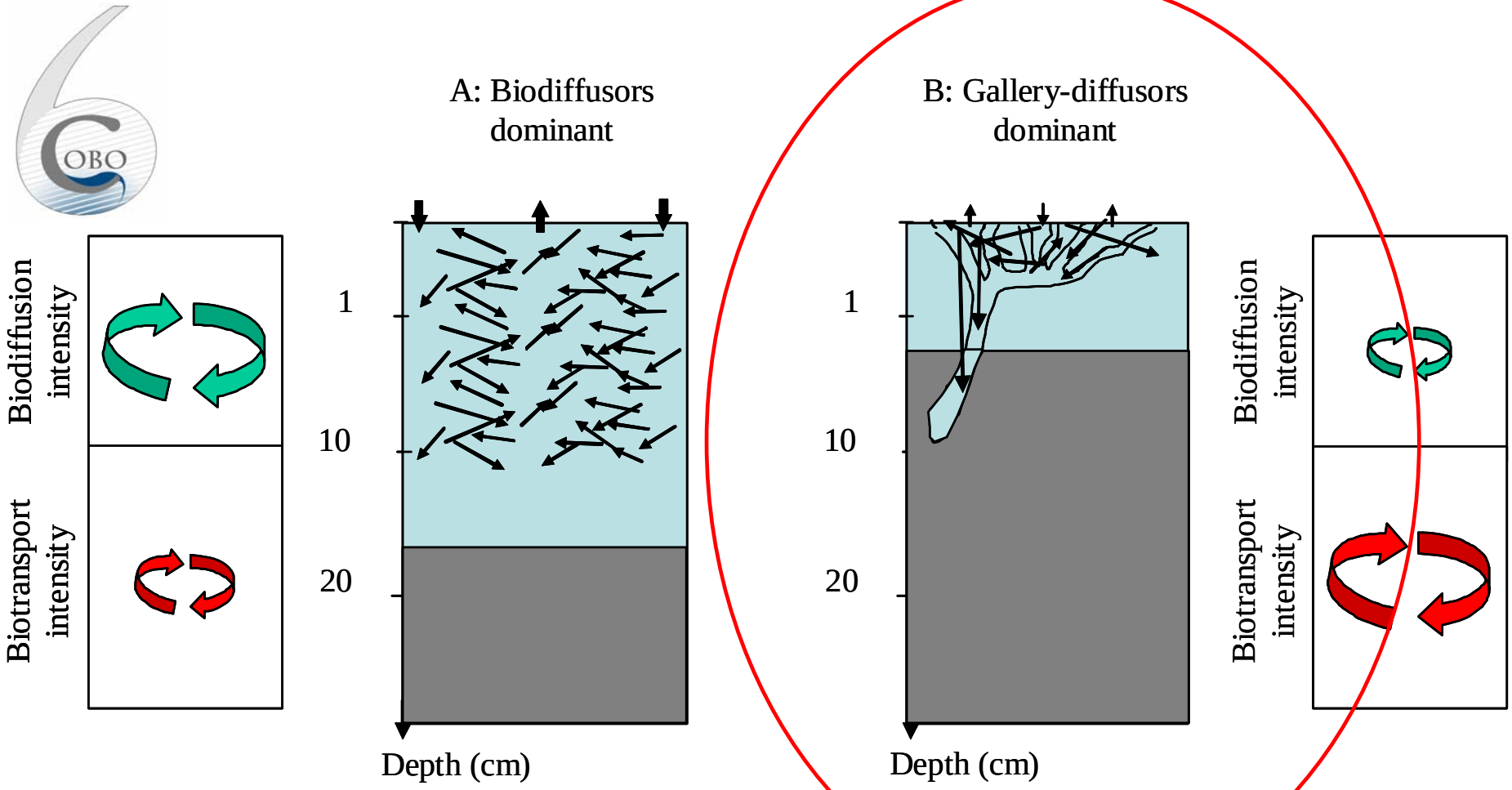
Organic enrichment can favour B-type, and can result in anoxia and sulphidic fish kills



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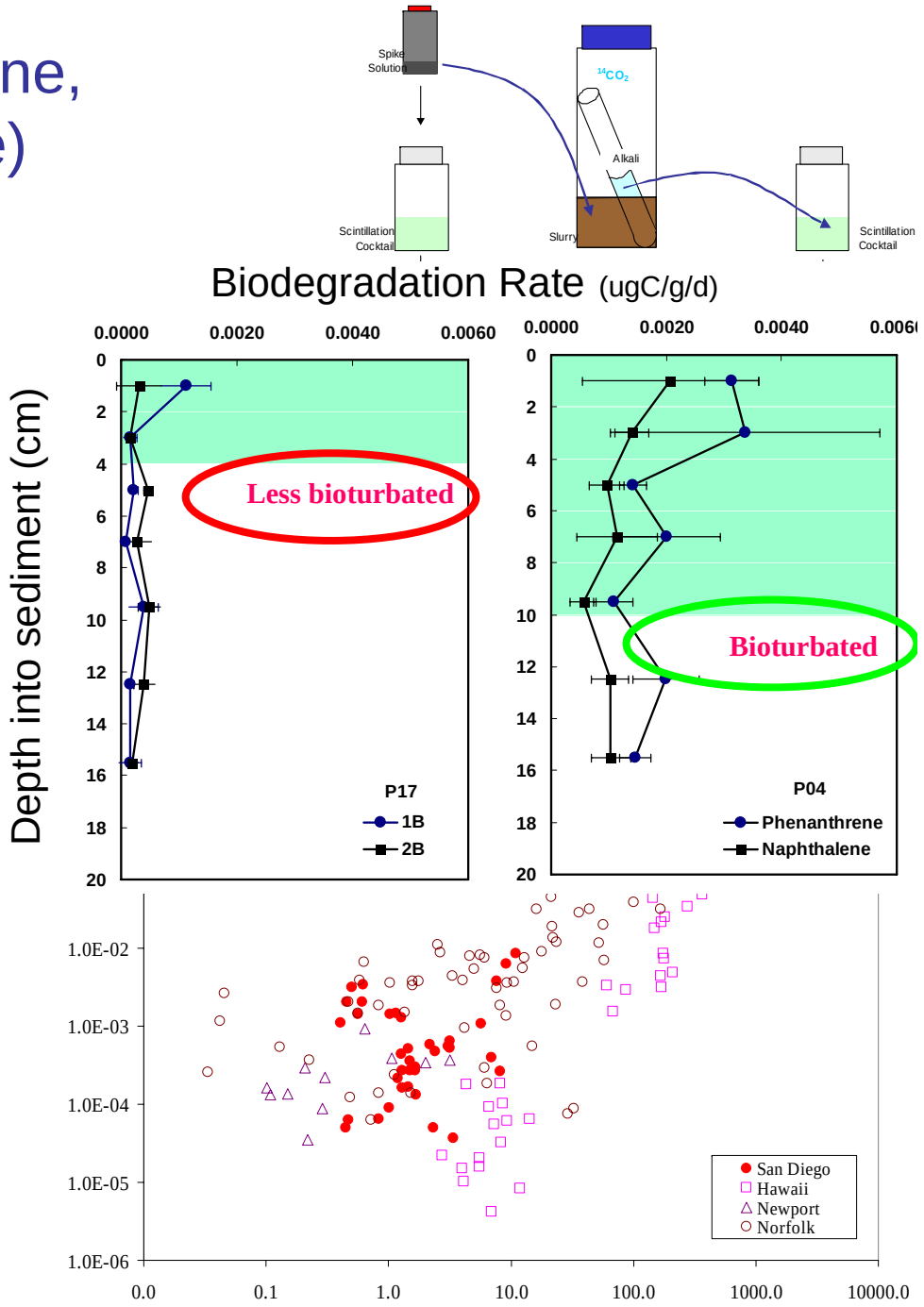
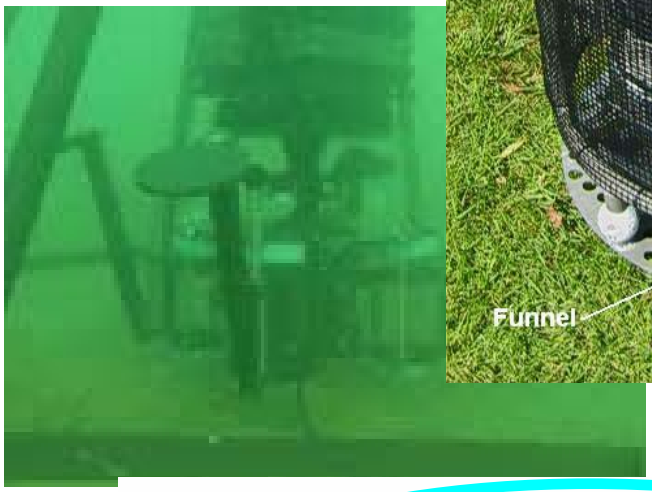
Degradation Rates (Naphthalene, Phenanthrene, Fluoranthene)

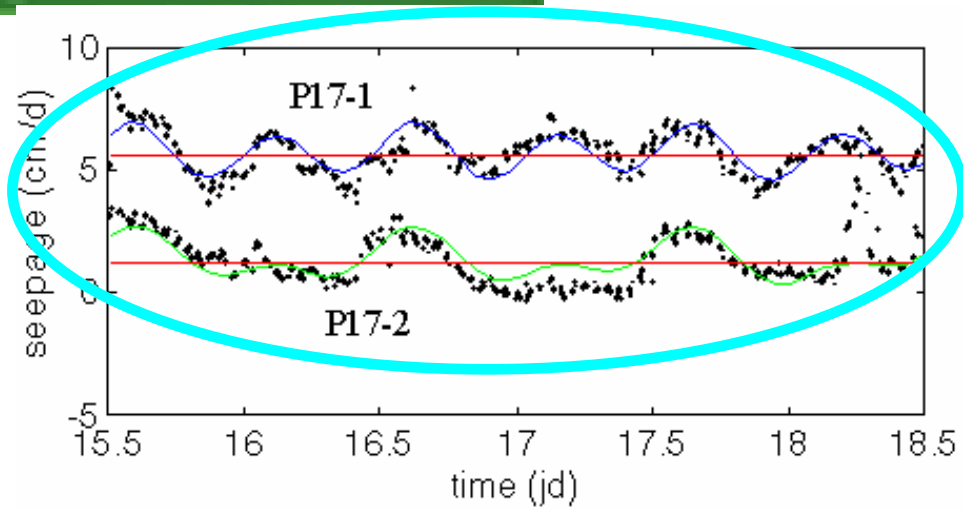
- Mineralisation rates generally stronger and extend deeper in more bioturbated sediment
- This is also observed when disturbance is anthropogenic or storm-induced



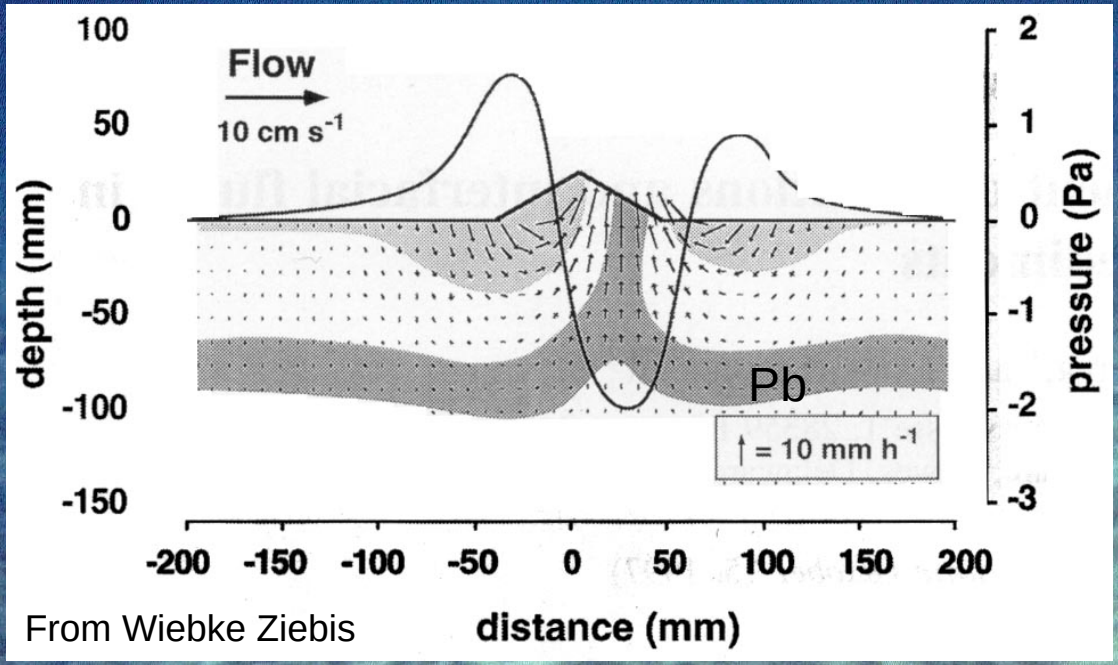
Advective Fluxes – mid-scale

- Direct measurement of seepage rates using ultrasonic seepage meters
- Advective flow can have tidal component
- Oxygen and nutrients are affected as well
- Can drive oxygen inputs, redox oscillation, nutrient balance, contaminant fluxes





Organisms alter the sediment structure, and thus the fluid and chemical fluxes



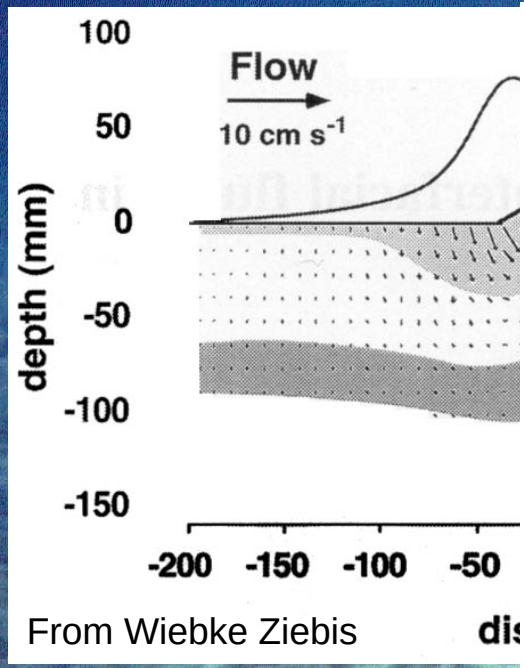
From Wiebke Ziebis

Flow-induced Advection: biogenically induced topography induces fluid flow, and thus localized redox states and chemical fluxes

In situ microelectrodes can map small-scale chemical gradients, elucidating these processes

from Joe Germano

Organisms alter the sediment structure, and thus the fluid and chemical fluxes



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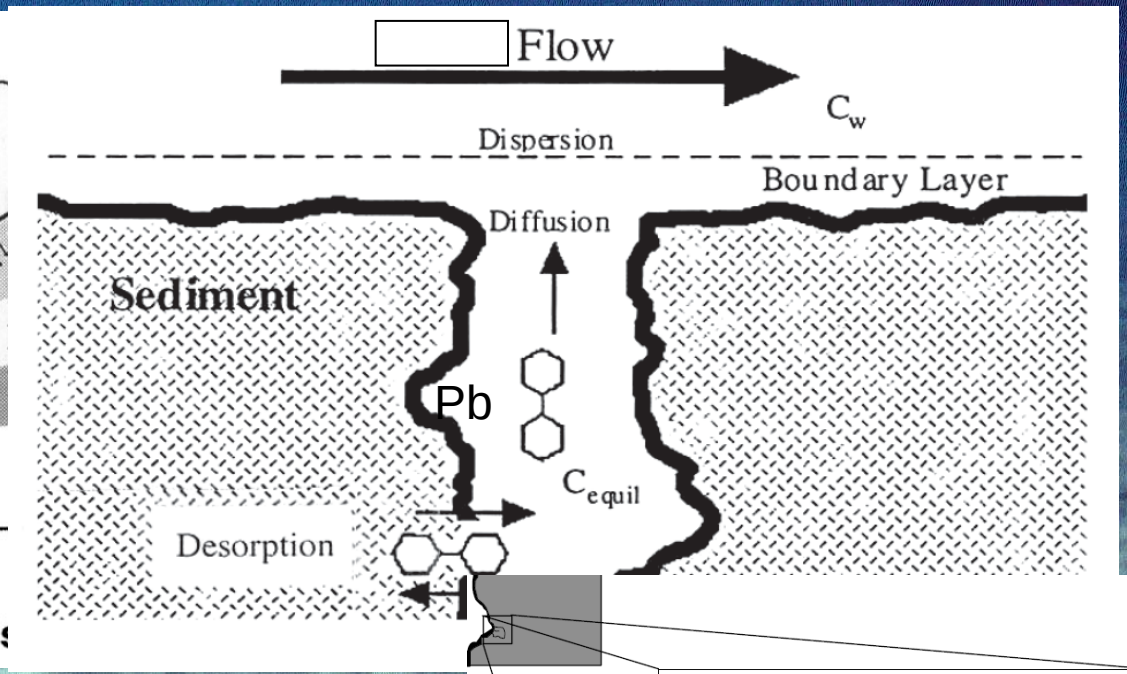
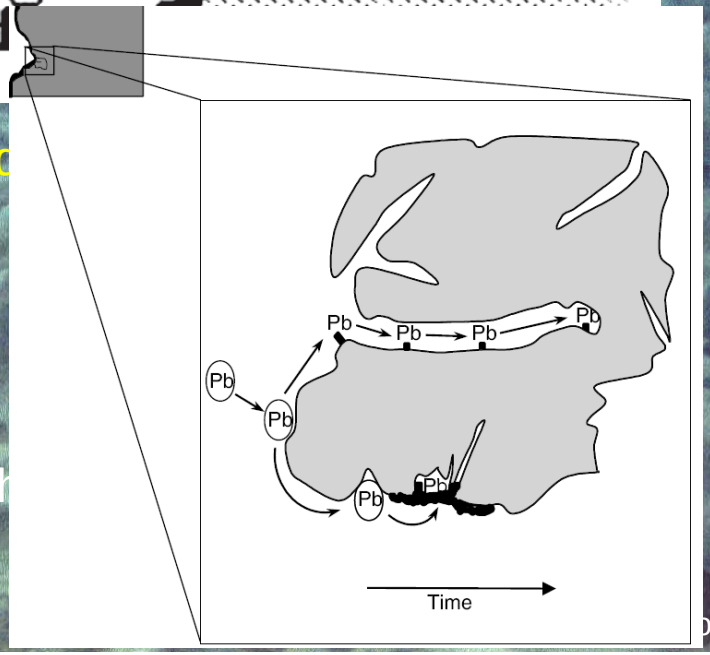


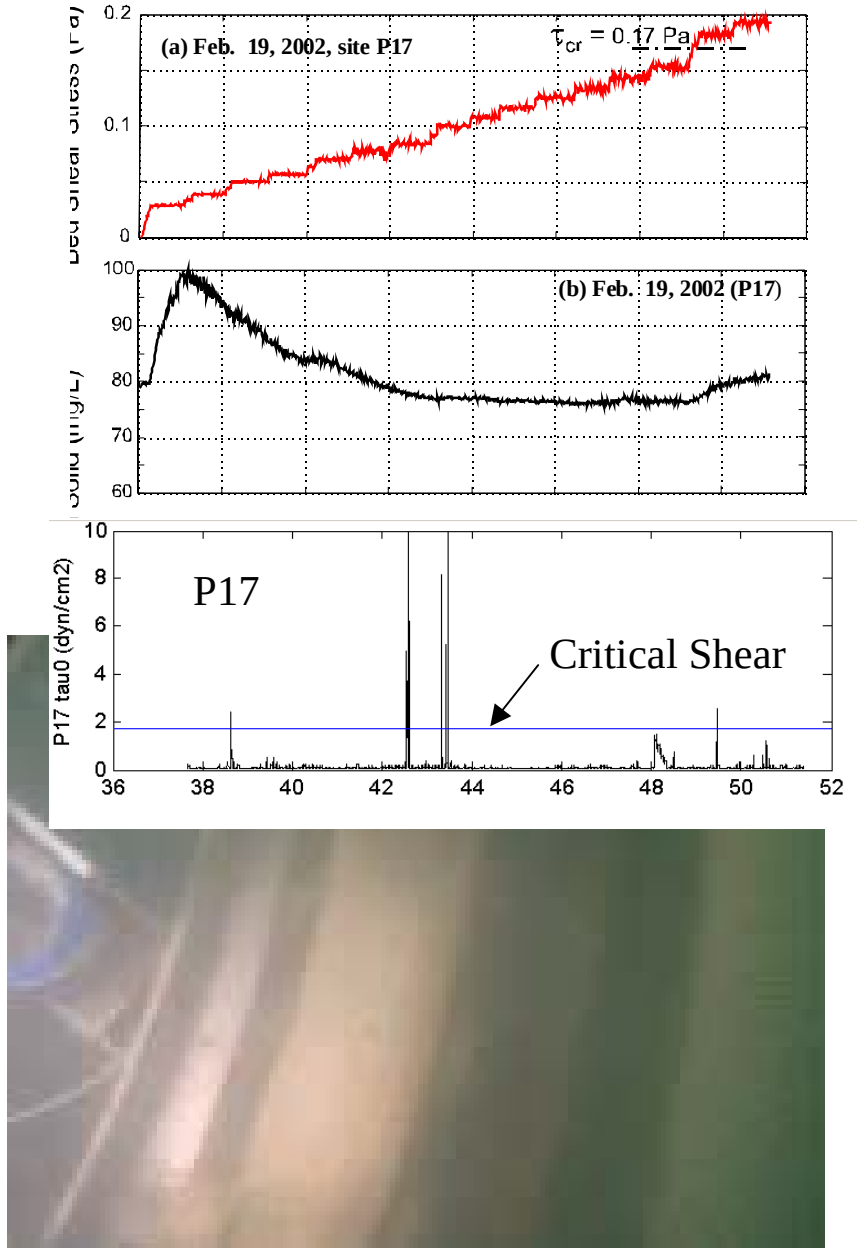


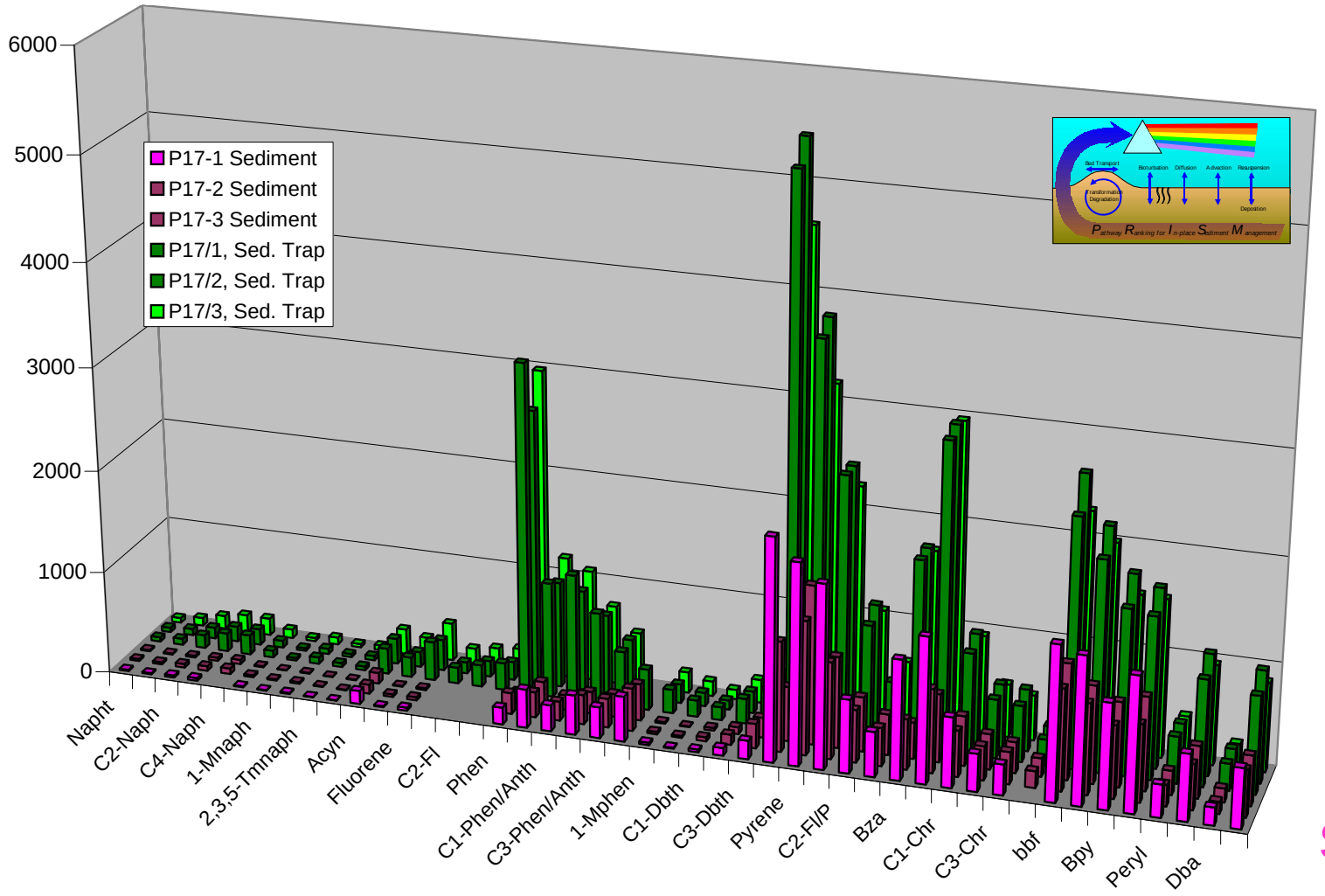
Flow-induced Advection: biogenically induced topography induces fluid flow, and thus localized redox states and chemical fluxes

In situ microelectrodes can map small-scale ch elucidating these processes

Erosive Fluxes

- Bed erosion properties (critical shear stress, erosion rates, currents, event frequencies) affect these processes
- Erosive potential during short periods (<1 h) associated with ship movements, storms, etc
- Erosion and settling can increase and/or decrease contaminant availability
- Affects stability, but also biophysical conditions





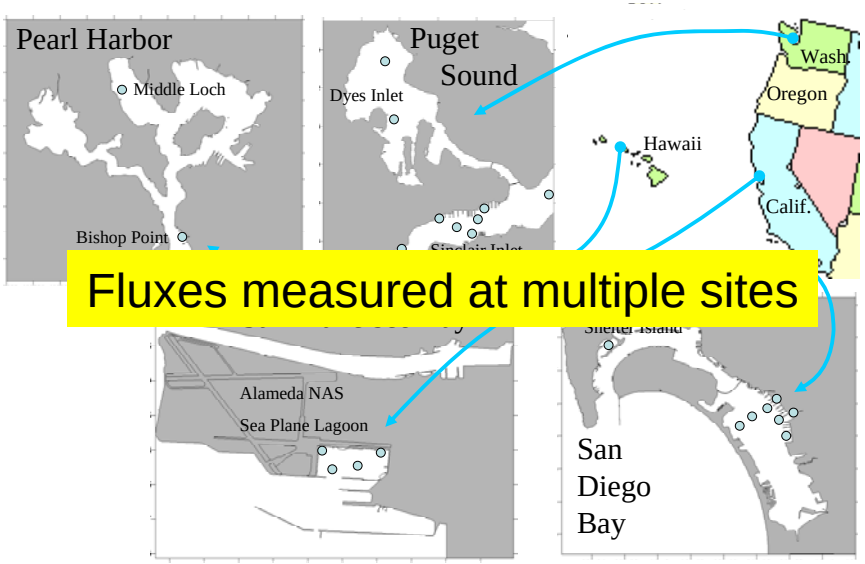
Evidence of rapid degradation of PAHs on sediments in the water column

Traps

Surface sediments

Resuspension may enhance degradation but also increase risk of desorption, transport and uptake

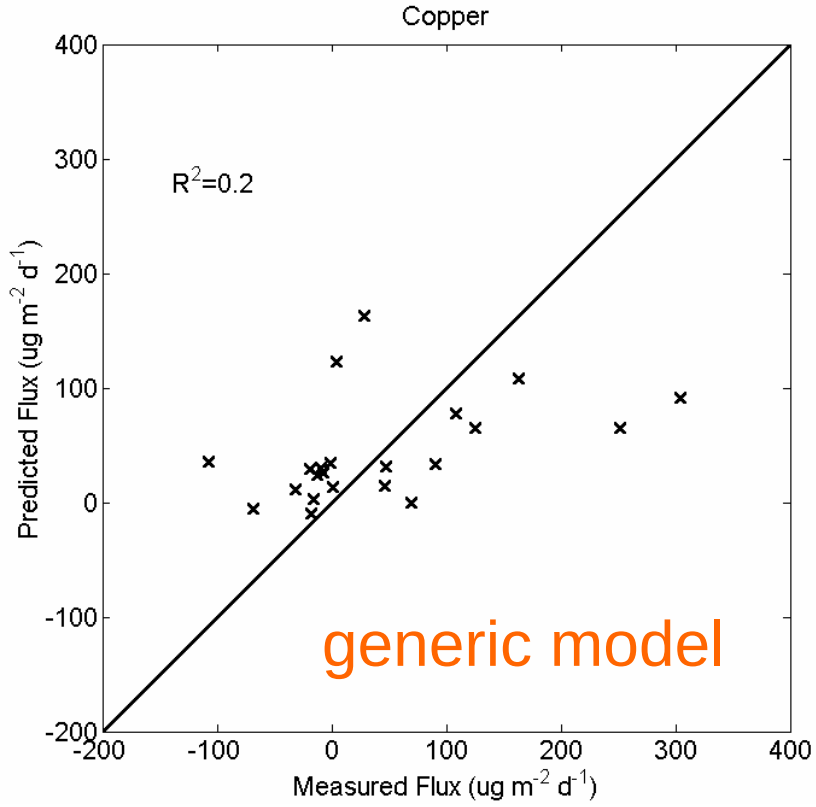
– these events may overwhelm diffusive or other fluxes

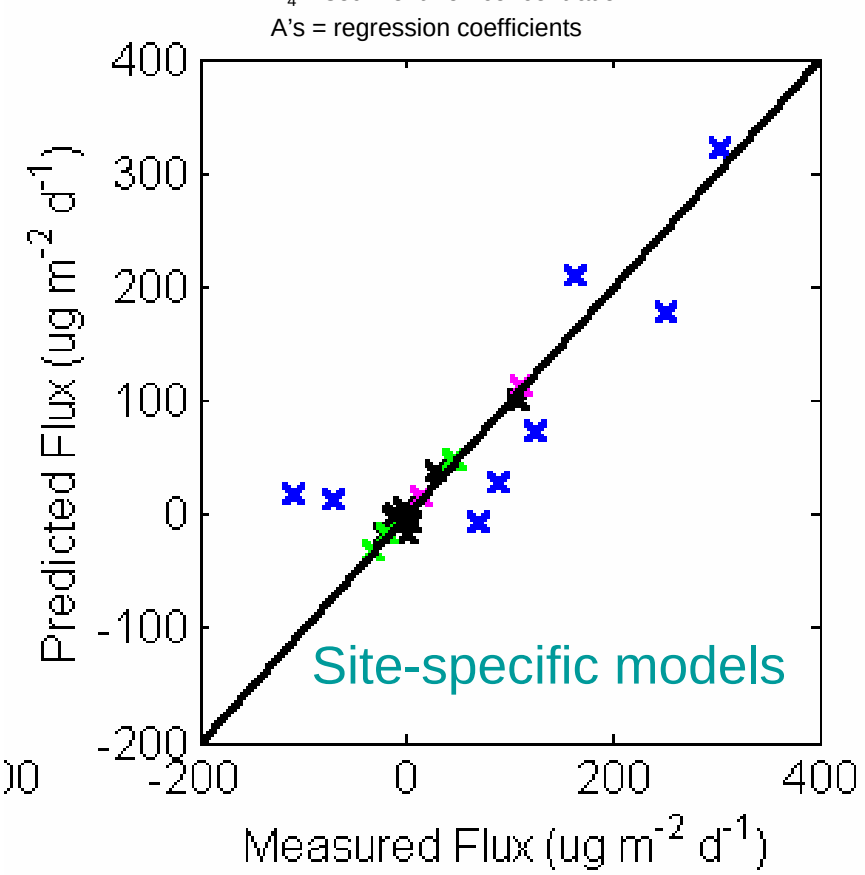


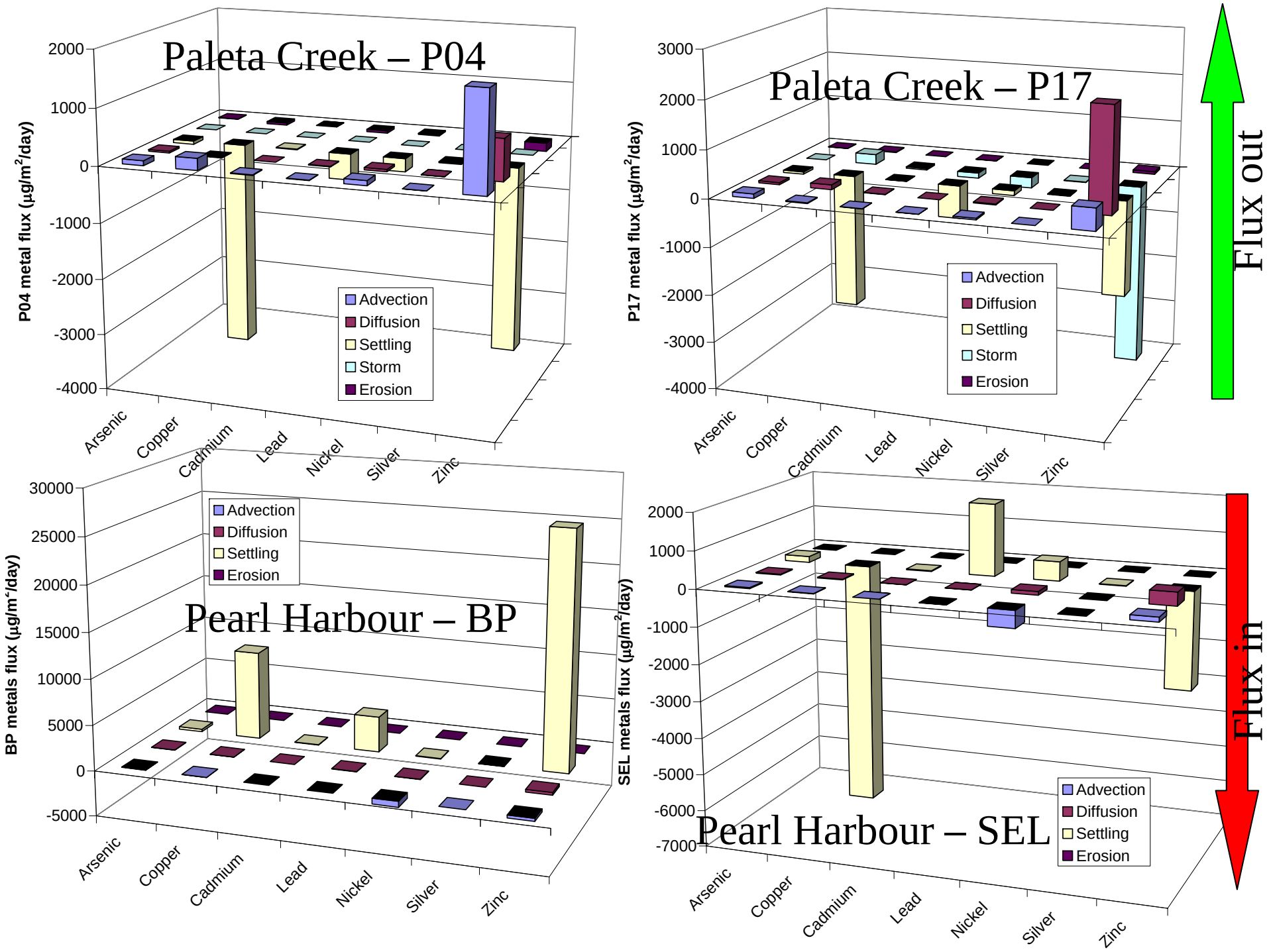
Contaminant fluxes could **not** be predicted from sediment characteristics using a generic model – interactions were site-specific

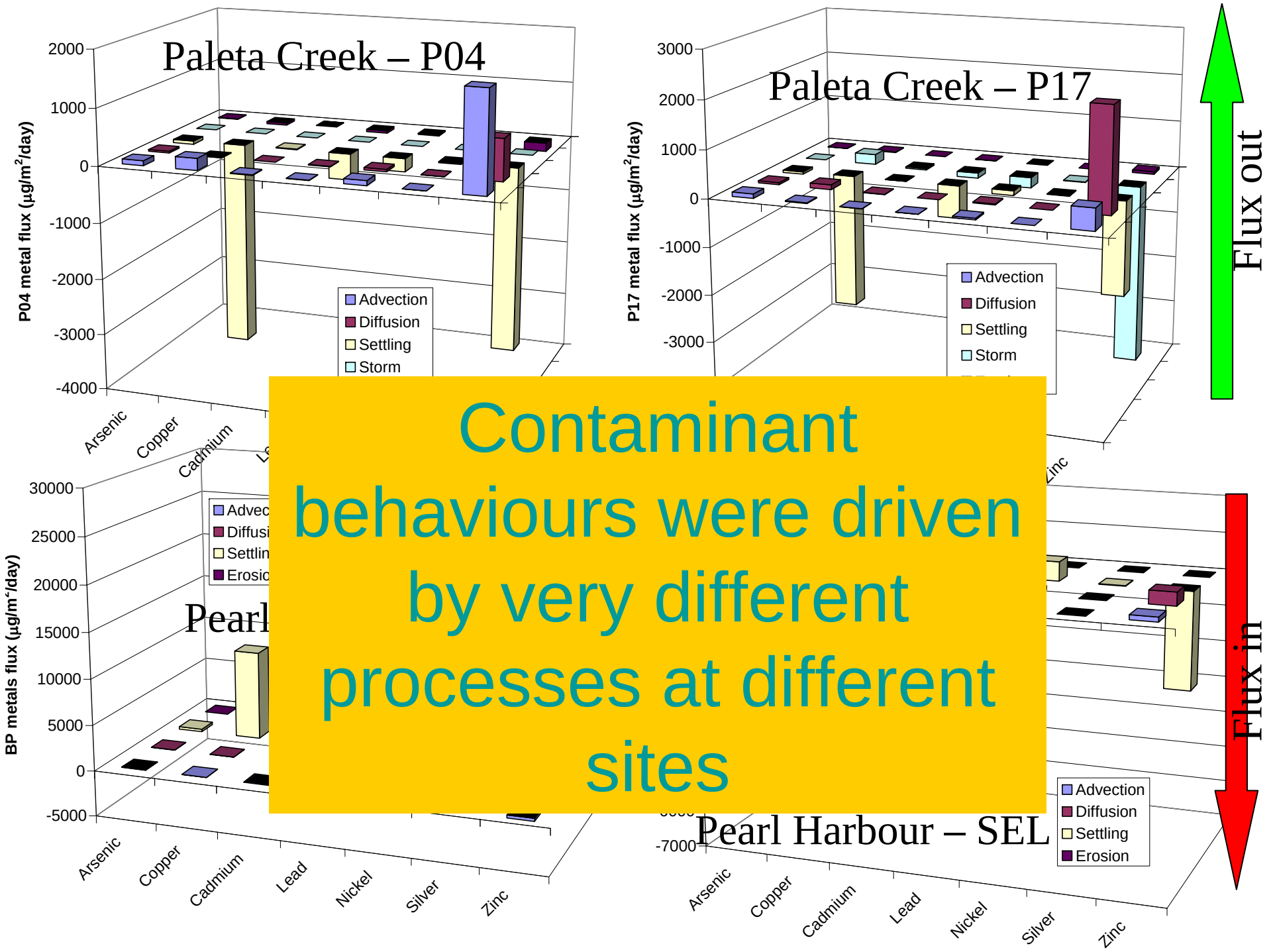
$$Y_{bf}=A_1X_1+A_2X_2+A_3X_3+A_4X_4+A_6$$

where Y_{bf} = predicted benthic flux
X_1 = sediment metal concentration
X_2 = % fines
X_3 = TOC
X_4 = sediment iron concentration
A's = regression coefficients






Paleta Creek – P04
P04 metal flux (µg/m²/day)
2000
1000
0
-1000
-2000
-3000
-4000
Advection
Diffusion
Settling
Storm
Erosion
Arsenic
Copper
Cadmium
Lead
Nickel
Silver
Zinc
Paleta Creek – P17
P17 metal flux (µg/m²/day)
3000
2000
1000
0
-1000
-2000
-3000
-4000
Advection
Diffusion
Settling
Storm
Erosion
Arsenic
Copper
Cadmium
Lead
Nickel
Silver
Zinc
Flux out
Pearl Harbour – BP
BP metals flux (µg/m²/day)
30000
25000
20000
15000
10000
5000
0
-5000
Advection
Diffusion
Settling
Erosion
Arsenic
Copper
Cadmium
Lead
Nickel
Silver
Zinc
Pearl Harbour – SEL
SEL metals flux (µg/m²/day)
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
Advection
Diffusion
Settling
Erosion
Arsenic
Copper
Cadmium
Lead
Nickel
Silver
Zinc
Flux in

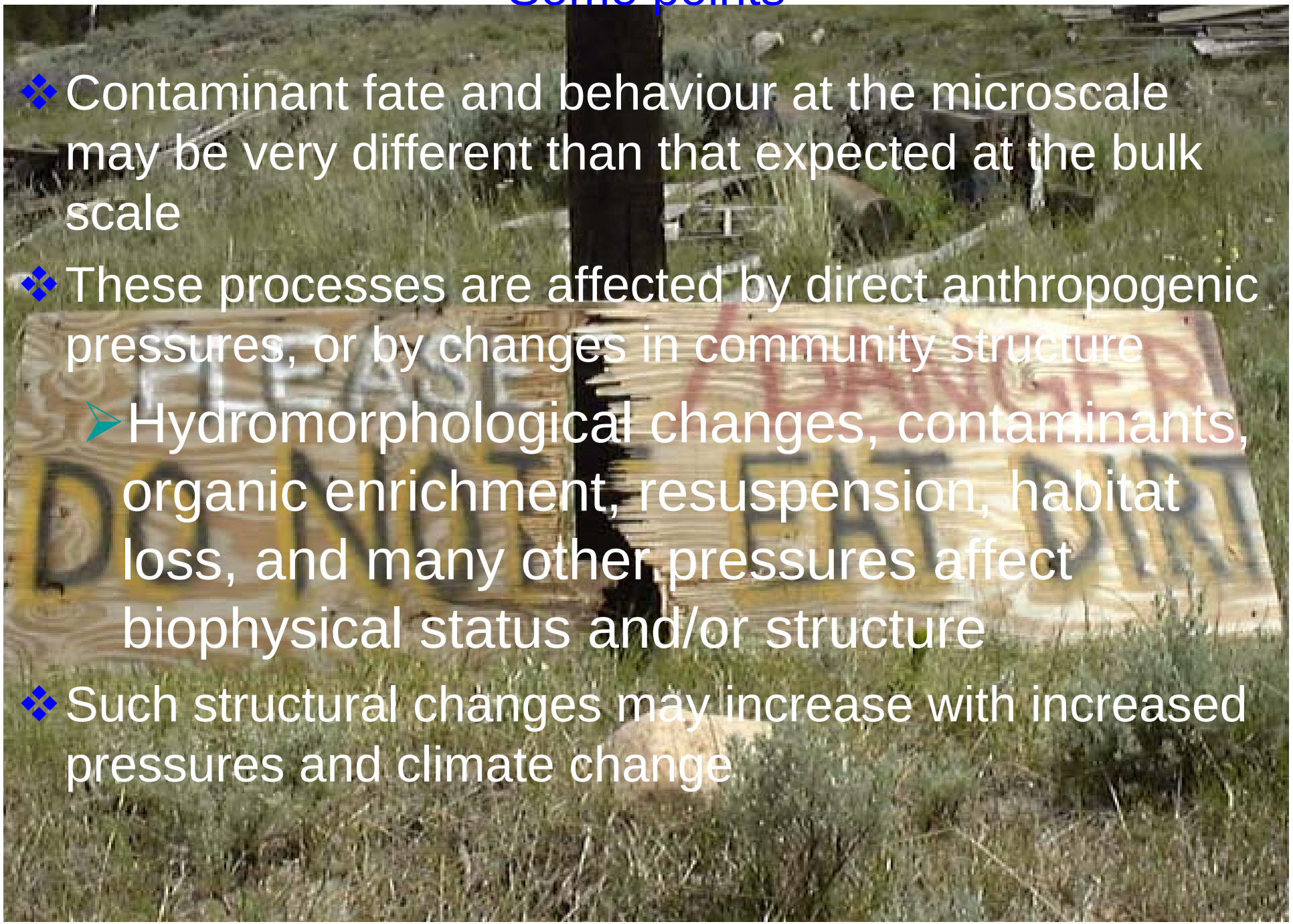

Paleta Creek – P04
P04 metal flux (µg/m²/day)
2000
1000
0
-1000
-2000
-3000
-4000
Advection
Diffusion
Settling
Storm
Arsenic
Copper
Cadmium
Paleta Creek – P17
P17 metal flux (µg/m²/day)
3000
2000
1000
0
-1000
-2000
-3000
Advection
Diffusion
Settling
Storm
Flux out
Contaminant behaviours were driven by very different processes at different sites
Pearl
BP metals flux (µg/m²/day)
30000
25000
20000
15000
10000
5000
0
-5000
Arsenic
Copper
Cadmium
Lead
Nickel
Silver
Zinc
Pearl Harbour – SEL
-7000
Advection
Diffusion
Settling
Erosion
Flux in

Biophysical changes can have positive and negative impacts

Dominant Process	Exposure	Attenuation	Example Control Strategies
Diffusion	Contaminant flux to biota	Contaminant attenuation	Reactive/sorptive cap Thicker cap Predict recovery
Bioirrigation	Contaminant flux to biota	Contaminant attenuation	Barrier
Advection	Contaminant flux to biota Contaminant flux to sediments from offshore	Contaminant attenuation O_2, nutrient delivery	Reactive/sorptive/impermeable caps Groundwater interdiction Predict recovery, Permeable cap
Erosion/Resuspension	Contaminated particle transport – site spreading Exposure to biota Desorption; redox osc.	Redox oscillation Mixing/dilution of contaminants Enhanced degradation (aerobic)	Removal, containment Predict bioremediation
Sedimentation	Continued input (if contaminated)	Burial (if clean)	Control source Predict recovery
Bioturbation	Exposure to biota Upward mixing Redox oscillation	Dilution O_2, nutrient delivery Redox oscillation	Barrier Predict Recovery
Biodegradation	Toxic metabolites	Loss of contaminants	Enhance biodegradation Avoid blocking O_2

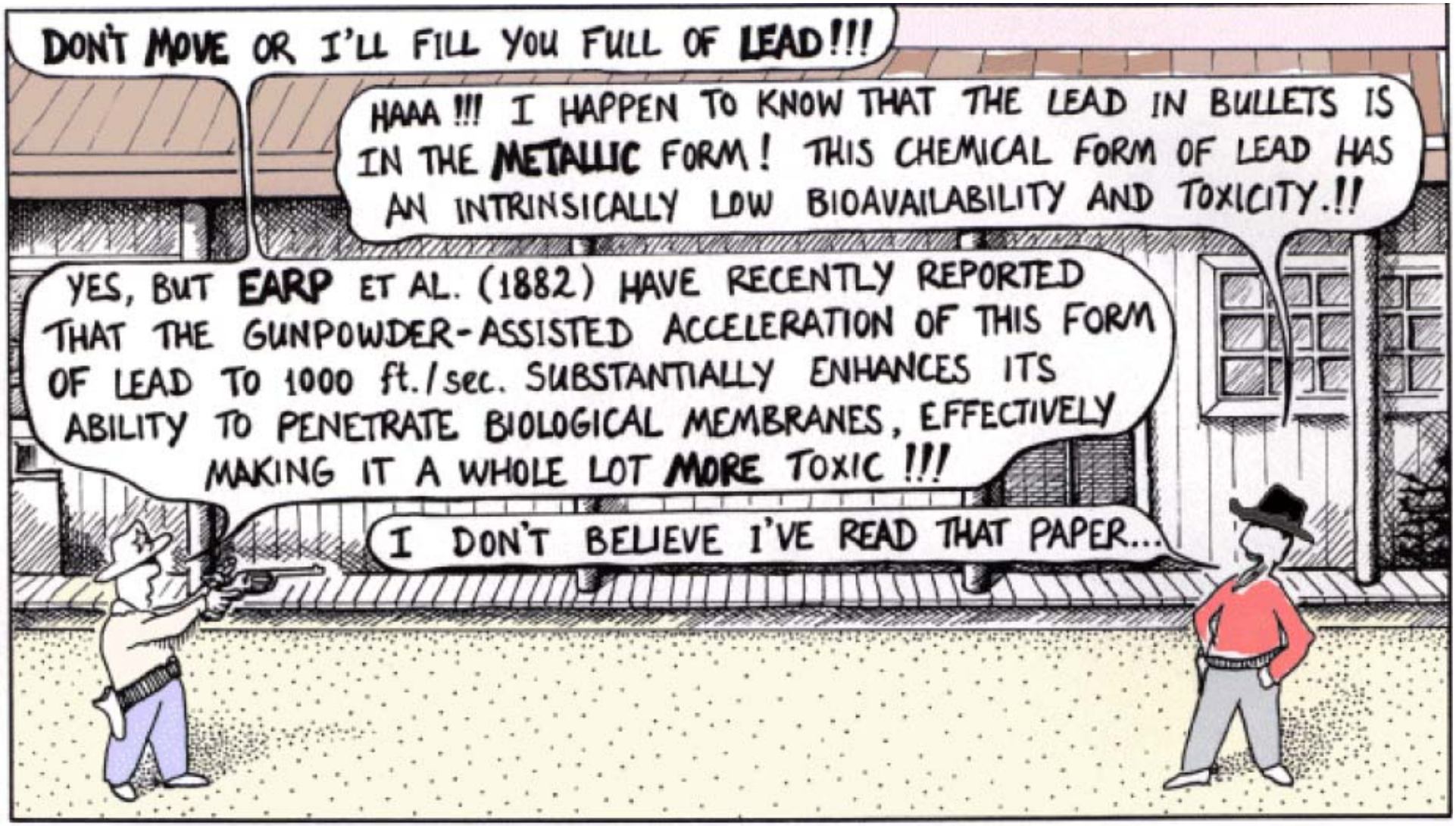
An understanding of the relative importance of contaminant transport processes at sites will focus site conceptual models and help risk managers balance these processes

Some points



- Contaminant fate and behaviour at the microscale may be very different than that expected at the bulk scale
- These processes are affected by direct anthropogenic pressures, or by changes in community structure
  - Hydromorphological changes, contaminants, organic enrichment, resuspension, habitat loss, and many other pressures affect biophysical status and/or structure
- Such structural changes may increase with increased pressures and climate change

Pathways of exposure ***can*** affect availability and mode of impact



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