

MS698–3: Sediment transport processes in coastal environments
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April 1, 2003

Lecture 11: Interactions with Biota

- Modification of flow field.
- Modification of sediment properties.
- Preservation potential.
- Bioturbation: biodiffusion, bioadvection.

Class business

Thu, April 3	Wheatcroft and Drake
Tue, April 8	Flocculation lecture
Thu, April 10	Winterwerp paper (Fugate leads)
Tue, April 15	Problem set 2 review
Thu, April 17	Consolidation lecture
Tue, April 22	Timescales lecture
Thu, April 24	Mulder and Syvitsky
Fri, April 25	Problem set 2 due
April 29	Term Papers Due by end of day

Materials used Dade et al. (2001); Wheatcroft (1990); Wheatcroft et al. (1990); Nittrouer and Sternberg (1981).

Introduction

Many aspects of sediment transport are impacted by interactions between organisms, the sediment, and the flow field. Quantifying these effects is the subject of much current research. Organisms influence the flow field by altering bottom roughness. They modify sediment characteristics by creating or breaking up aggregates, and by coating sediments with organic matter. They also modify the structure of the sediment bed by burrowing activities.

In general, silty and muddy beds are more impacted by biogenic processes than are sandy beds. Fine grained beds do not travel as bedload, so the ability for physical processes to build roughness elements is limited on muddy beds. Benthic organisms are also more likely to ingest and pelletize fine-grained material than they are sands. Sandy beds can be impacted by biogenic processes, however, if their roughness is dominated by mounds, or if they are vegetated.

Biological effects to flow field

Dade et al. (2001) summarize, and review recent studies of how biota influence the turbulence and velocity field near the seafloor. In general, biota greatly increase the physical roughness of the seafloor (k_b), and thereby the hydraulic roughness (z_0) compared to the roughness of a flat bed. The increased roughness comes from (1) pelletization of sediment into coarser aggregates by benthic organisms, (2) the presence of bio-genic mounds or tracks, (3) protrusion of the organisms into the flow (worm tubes, grasses). These can be quantified following analogs to the physical forms that we studied earlier.

Biogenic roughness

The roughness created by a fecal pellet is estimated in the same way that we derived the Nikuradse grain roughness for quartz grains. Roughness created by biogenic mounds and tracks has been observed increase the roughness of a flat bed by factors of two to ten. Evidence also indicates that, while a biogenically dominated bed may become “flattened” during energetic flows, the biota re-disturb the bed within hours to days of quiescent conditions. To account these types of roughness elements, Wiberg et al. (1994) recommends using a minimum value of hydraulic roughness equal to $z_{0,min} = 0.005cm$ for muddy-silty shelf sediments, while Dade et al. (2001) cite a minimum value of $k_b = 0.1cm$ for deep-sea environments. Wiberg’s approach involves classifying the seabed as being either physically or biogenically dominated. For biogenically dominated beds, the geometry (height η_{bio} , and wavelength λ_{bio}) of background roughness elements (tracks and mounds) is estimated from intuition or bottom photographs. The physical roughness of these is then estimated in a manner analogous to a rippled bed, $k_{bio} = \eta_{bio}^2/\lambda_{bio}$, and hydraulic roughness then estimated based on the roughness Reynolds number. Because these tracks and mounds are likely to degrade during energetic flows, Harris and Wiberg (1997) included erosion of mounds and tracks so that the bed flattens as shear stresses increase.

Besides modifying the sediment surface, benthic organisms can act as roughness elements themselves. Worms, grasses, and benthic-dwelling organisms can dominate the physical roughness of sediment beds. Laboratory and field studies have been used to relate the size and spacing of such organisms to hydrodynamics of the surrounding flow. To review work from VIMS, see, for example Wright et al. (1997); Schaffner et al. (2001). For discussions on how vegetation influences drag and turbulence, see work by Heidi Nepf and her students (<http://web.mit.edu/nepf/www>).

Biogenic form drag

Large scale biogenic roughness (mounds, tracks, large organisms, etc.) can create form drag in a manner similar to ripples and dunes. Separation of the form drag and skin friction from total shear stress should be done to estimate shear stresses that operate on sediment grains. The drag coefficient used (C_D)

to estimate form drag would depend on the shape of the biogenic roughness element.

Modification of sediment properties

Organisms pelletize fine-grained material, and in some cases, such as the Palos Verdes shelf, fecal pellets are the dominant sediment type (Drake et al., 2002). In addition to modifying sediment grain roughness, repackaging sediment into pellets tends to decrease the sediment-grain density, but increase settling velocity (relative to un-pelletized grains).

Binding by microbes can increase the critical shear stress for transport (τ_{cr}) of marine and estuarine sediments by up to a factor of 4 (Dade et al., 2001). Such processes often have seasonal cycles. Bindings may form during quiescent, productive summer seasons, and then be broken down during energetic (winter) storms. The timescale for growth may be fairly long, so that critical shear stress for a sediment bed may be modified over the growth-timescales, as well as over seasonal timescales.

Bioturbation

I usually use the term *bioturbation* to refer to physical modifications to sediment-bed structure by benthic organisms. Feeding and burrowing activities of benthic organisms cause sediment to be mixed and transported within the seafloor. The literature distinguishes between *bio-advection*-which moves sediment up or down in the seabed; and *biodiffusion*- which mixes sediment. Different types of organisms and activities would set up different transport paths (advective or diffusive) within the sediment bed. Sediment core profiles of radio-isotopes have been used to infer mixing rates. While mixing in the seabed is the product of both bioturbation and physical mixing (through cycles of resuspension and redeposition, and bedform migration), mixing coefficients are backed out of sediment cores to estimate *biodiffusion coefficients*, D_b . These are mixing coefficients (L^2/T); the larger D_b , the quicker biota can mix sedimentary layers. Typical D_b range from 100 – 0.01 cm^2/yr (Wheatcroft, 1990).

Bioturbation tends to be limited to surface sediments, in the region called the *surface mixed layer*. Typical thicknesses of this layer are on the order of 1 – 100 cm (Wheatcroft, 1990), with a value of 10cm often being used for shelf sediments.

Using a scaling argument, Wheatcroft et al. (1990) conclude that bioadvection by large organisms (mostly deposit feeders) is likely to dominate biogenic mixing of sedimentary layers. Mixing is anisotropic, with horizontal dominating over vertical mixing. Most vertical mixing is advective. The geochemical profiles that result from bioadvective processes, however, act to create similar isotopic profiles in sediment cores. The use of inferred biodiffusion coefficients is therefore cautioned against by Wheatcroft et al. (1990).

I used biodiffusion coefficients from the mid-shelf off of northern California to predict how quickly bioturbation would obliterate storm beds for continental

shelf environments off of California. The results showed that inferred mixing rates were capable of wiping out storm beds within a few weeks of deposition (Harris and Wiberg, 1997). For a sedimentary structure to be preserved on a modern shelf therefore requires that it be thicker than the depth of bioturbation, or be capped by another event layer within weeks of deposition.

Preservation Potential

Bioturbation rates and lengthscales become important when the *Preservation potential* of an event bed is considered. This describes the likelihood that a sedimentary layer will be preserved by burial, as opposed to becoming obscured by biogenic or physical disturbances. Nittrouer and Sternberg (1981) argue that two coefficients (G and H) can be used to quantify the ability of bioturbation and physical mixing processes to destroy event layers. Both G and H compare the speed of mixing to accumulation rate:

$$\begin{aligned} G &= \frac{D_b/L_b}{A} \\ H &= \frac{f_p L_p}{A} \end{aligned} \tag{1}$$

where D_b is a biodiffusion coefficient, L_b is the depth of the biogenically mixed layer, A is accumulation rate, f_p is the frequency of resuspension, and L_p is the depth of the resuspended layer. High values of G and H indicate that biogenic or physical reworking will destroy sedimentary layers before sufficient accumulation caps them.

Methods for dealing with sediment / animal interactions

To include the influences of benthic organisms, including vegetation and microbial communities, in sediment transport calculations requires that we quantify the physical effects caused by the biota. Lab studies can help to relate fluid dynamic properties (drag, roughness) to biogenic substrates. Field surveys are critical for characterizing sediment characteristics in areas impacted by organisms.

References

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