Inclusion of Multiple Functional Types in an Automaton Model of Bioturbation and their Effects on Sediments Properties

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LONG-TERM GOALS

The long term goal is a quantitative and mechanistic understanding of the relationship between infaunal ecology and the consequent modification of sediments, including the creation and destruction of heterogeneities and the modes and rates of sediment component mixing.

OBJECTIVES

The development of an individual-based model (computer code) of sediments and organisms that utilizes biologically relevant parameters, such as animal sizes, population density, feeding and locomotion rates, and probabilities for observed behavior(s), to drive the model and produce predictions about sediment composition and fabric.

APPROACH

Biologically active sediment is represented on a computer as a regular lattice of quasi-particles with individually assigned chemical, biological or physical properties. Model benthic organisms are introduced in the form of automatons, i.e. programmable entities, that are capable of moving through the particle lattice by displacing or ingesting-defecating particles. Each automaton obeys a set of rules, both deterministic and stochastic, designed to mimic real organism behavior, with different types of organisms having different sets of rules. The acronym for the model is LABS (lattice-automaton bioturbation simulator).

WORK COMPLETED

Funding from ONR Grant # N00014-02-1-0107 has supported the development of a lattice-automaton model of bioturbation (LABS). Work in 2007 was the result of a "no cost" extension. The extension permitted the writing and acceptance of two more publications, i.e., Huang et al. (in press, JMR) and Reed et al. (in press, JMR). In addition Dan Reed who has been supported by this grant will defend his PhD Thesis on 9 November 2007.

This is the **FINAL REPORT** on this grant.

SCIENTIFIC RESULTS

1) LABS-based results. The end of ONR support terminates the development of the ecology in the LABS model. However, the model includes small deposit feeders (Fig. 1A), two types of head-down deposit feeders (Fig. 1B,C), and fiddler crabs (Fig. 1D).

The data generated by LABS is already having an important influence on our understanding of bioturbation. Bioturbation is extremely difficult to study because measurements of mixing rates and effects are difficult and time-consumming to make in real sediments and the medium is opaque to visual observation. LABS can generate synthetic data sets of tracers, porosity, etc., distributions in mixed sediments, where we have complete knowledge of the modes and rates of biological actions *a priori*. The data sets can then be analyzed with traditional models of bioturbation (biodiffusion, non-local, etc.) to determine if the traditional models adequately parameterize and characterize the actual mixing.

As an example of the application of this method, we have shown that the supposed faster mixing of shorter-lived tracers in sediments, termed "age-dependent mixing" by C.R. Smith et al. (1993, Geochimica et Cosmochimica Acta), can result from a failure of the assumptions behind the diffusion model when applied to the short-lived isotopes, and not a biological effect.

Similarly, using transient steady tracers in LABS, we have been able to show that the mixing coefficient values calculated from the evolving tracer distibution falls as a function of time, see Fig. 2, and reaches the true value calculated from total particle tracking only after 150 days (for the chosen experiental conditions). This finding is broadly true for a wide set of environmental conditions and is again related to misuse of the biodiffusion model. Because these result awill severely impact the use of the diffusion model to describe short-lived isotopes in sediments, we are developing, in collaboration with F. Meysman, a new different way to parametrize mixing of short-lived tracers - see the submitted paper Meysman et al. (submitted-a, JMR).

Using the lattice-automaton model, we have also simulate the effects of fiddler crabs on the distribution of excess ^{210}Pb in marsh sediments. Three modes of bioturbation were identified and investigated: (1) *removal-and-fill*, where material is excavated to the sediment-water interface and burrows are subsequently filled by surface material when abandoned, (2) *removal-and-collapse*, where the infilling occurs by collapse of the burrow walls, and (3) *partial-compaction-and-collapse*, where part of the excavated sediment is packed into the burrow wall and abandoned burrows subsequently collapse. These various mixing modes lead to somewhat different laterally-integrated $^{210}Pb_{ex}$ profiles, which are also influenced by burrowing frequency, burrow dimensions, fraction of surface material replaced by new sediment (regeneration), and the fraction of material compacted during burial.

Using parameters from a previous study of $^{210}Pb_{ex}$ in a South Carolina marsh, we found that data from low marsh sites are best predicted by the partial-compaction-and-collapse process, which is consistent with the observation that burrow casts indicate far more material is excavated than is deposited as pellets on the sediment-water interface. The profile from the high marsh site is best simulated by removal-and-fill mixing with 50% regeneration of material at the sediment-water interface; this is consistent with less frequent flooding at this site.

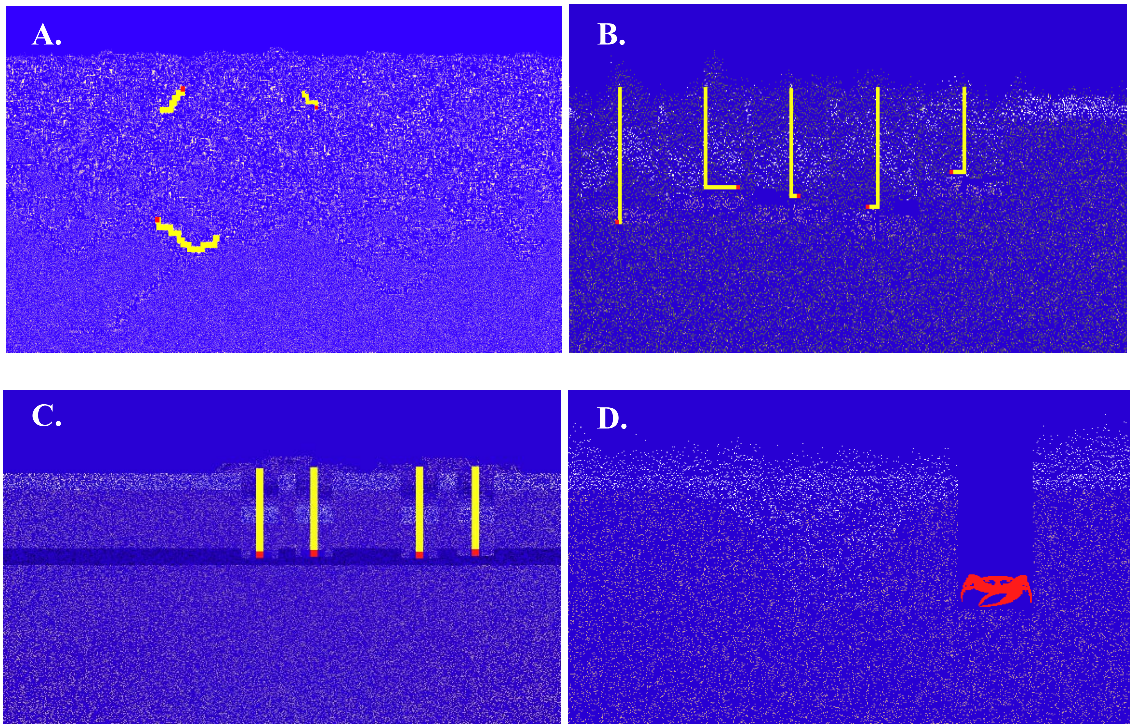

Figure 1. "Screen shots" of different types of benthic organims found in LABS. Diagram A – simple small deposit feeders, similar to capatelids. Diagram B – head-down deposit feeders with sideways feeding. Diagram C – purely vertical head-down deposit feeders. Diagram C – fiddler crab (burrow-and-fill mixing).

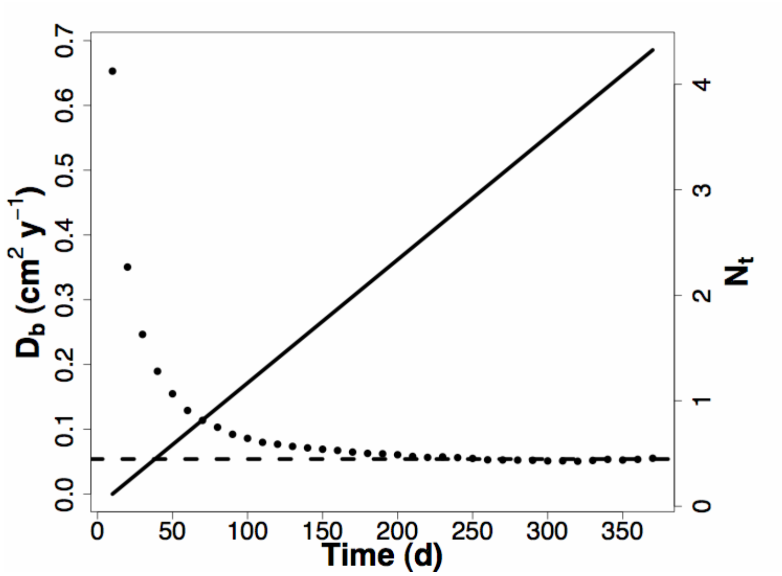

Figure 2. The mixing coefficient, Db, derived using the standard biodiffusion model applied to a transient tracer (Reed et al.,2006). The temporal trend in the black dots is again due to violation of the assumptions inherent to the diffusion model. The dashed line is the actual D_B from total particle tracking in LABS.

We have also calculated the exchange function for each of these mixing modes and show that they are highly asymmetric, indicating that the mixing is not diffusive. Only in the case of partial-compaction-and-collapse does the exchange function approach a diffusive form when the excavation rate decreases, i.e., the probability of compaction increases.

2) *Deterministic Modelling Results.*

As noted above, we are working on a stochastic method of modelling transient and short-lived tracers. This has resulted in two submitted papers, i.e., Meysman et al. (submitted-a, JMR) and (submitted - b, GCA).

IMPACT/APPLICATIONS

Our results will prove to be highly significant to understanding of contaminant movement in sediments and to acoustic seafloor imaging, i.e., studies of heterogeneity.

RELATED PROJECTS

We have worked in collaboration with Peter Jumars (Univ. Maine), and his PhD student Kelley Dorgan, who are measuring animal locomotion rates and modes of movement. Their results are used as inputs into our model.

PUBLICATIONS (Cumulative)

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