Quantitative Chemical Mass Transfer in Coastal Sediments During Early Diagenesis: Effects of Biological Transport, Mineralogy, and Fabric

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LONG-TERM GOAL

The long-term goal is to develop a better mechanistic and quantitative understanding of the effects of biologically-enhanced transport, mineralogy, sediment fabric, and particle surface chemistry on the biogeochemical dynamics of coastal marine sediments.

OBJECTIVE

The objective for FY98 was to develop methods to quantify the transport processes in cohesive coastal sediments based on fabric data. The short-term goals for the accomplishment of this objective included (1) the synthesis of data obtained during the FY97 field study in the Dry Tortugas, Florida, in terms of biologically-induced pore water mixing, (2) completion of field studies in fine-grained coastal environments, and (1) quantitative description of pore water and sediment mixing and biologically-induced fabric heterogeneity for the new field site.

APPROACH

The synthesis of FY97 field data was conducted using the burrow irrigation model developed by Aller (1980) in conjunction with fabric data and STEADYSED1 (Van Cappellen and Wang, 1996), a reactive transport model for early diagenesis. Sediments of the new field site, a muddy estuary near Bay St. Louis, Mississippi, were investigated using the field and modeling techniques developed during the FY97 Dry Tortugas study. The techniques include centimeter resolution pore water analyses using sediment core slices and deployment of ^{13}C-labeled particle tracers. The study was conducted in close collaboration with D. Lavoie (also funded by ONR 322GG) who characterized the sedimentological and fabric parameters of the study area sediments.

WORK COMPLETED

The synthesis of FY97 cruise data from Dry Tortugas for the comprehensive modeling of pore water transport was completed in collaboration with D. Lavoie and P. Van Cappellen (also funded by ONR 322GG), and is currently prepared for publication. The data synthesis for the biologically-induced particle mixing in Dry Tortugas is still underway.

Seven field trips to the Bay St. Louis site were completed. In situ and post-sampling analyses were conducted for bottom water chemistry, pore water chemistry, and solid phase chemistry. Most of the

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data have been compiled, as shown below in the RESULTS section below. The dissolved metal data are still being analyzed. The physical properties (porosity, grain size distribution, and permeability) were analyzed by D. Lavoie. The sediment fabric at both centimeter and sub-millimeter scales was sampled and is being characterized by D. Lavoie. The deployment of ^{13}C-labeled deliberate tracer was also conducted, and spatial distribution of the tracer resulting from biological particle mixing is being analyzed.

RESULTS

Spatial distribution of pore water species in the carbonate sediments of Dry Tortugas was characterized by the lack of depth-dependent decrease of SO_4^{2-} and presence of subsurface peaks in pore water NH_4^+ and ΣCO_2 profiles. The latter profiles were modeled by STEADYSED1 using the quantitatively parameterized combination of (1) pore water irrigation and (2) depth dependent organic carbon degradation rate. Pore water irrigation (1) was modeled with the non-local advection model (Boudreau, 1997) with the parameter values indicating extremely active irrigation throughout the sampling depths. Organic carbon degradation rate (2) was modeled by assuming two separate groups of organic matters with significantly different reaction rates. The depth profile of dissolved O_2, one of the most important redox species, could not be adequately modeled using the non-local advection model, and was fist modeled using the irrigation model of Aller (1980) and forced into STEADYSED1. These calculations yielded depth profiles for NH_4^+, ΣCO_2, and pH very close to the measured profiles as shown in Figure 1.

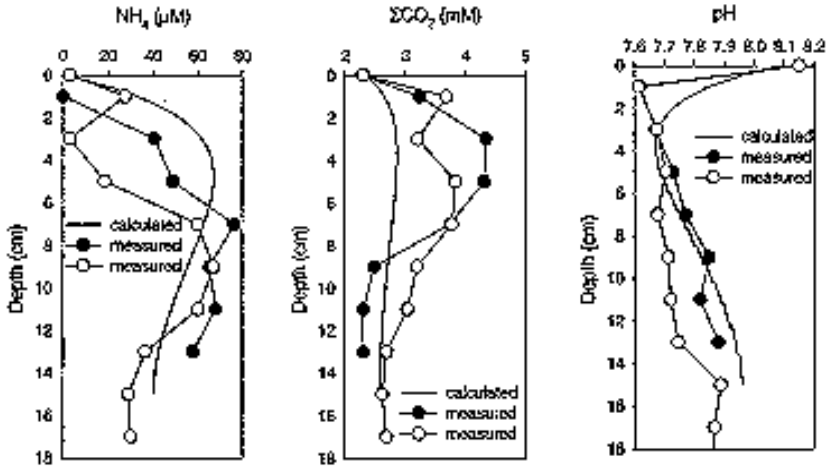

Figure 1. The NH_4^+, ΣCO_2, and pH profiles calculated using STEADYSED, with the input organic carbon degradation rate (R) modeled as $R = R_0 \exp(\beta_0 x) + R_1 \exp(\beta_1 x)$, in which x is the depth. The values of parameter R_0, R_1, β_0, and $\beta 1$ are 1277, -14.3, 40, and –0.05, respectively. The measured profiles are shown for comparison.

The spatial distribution of pore water species and particulate organic carbon from three locations within the muddy estuary near Bay St. Louis exhibited the profiles shown in Figure 2. These data will be used in conjunction with the fabric and permeability data from Lavoie and STEADYSED1 from Van Cappellen to model the pore water and sediment transport during FY99.

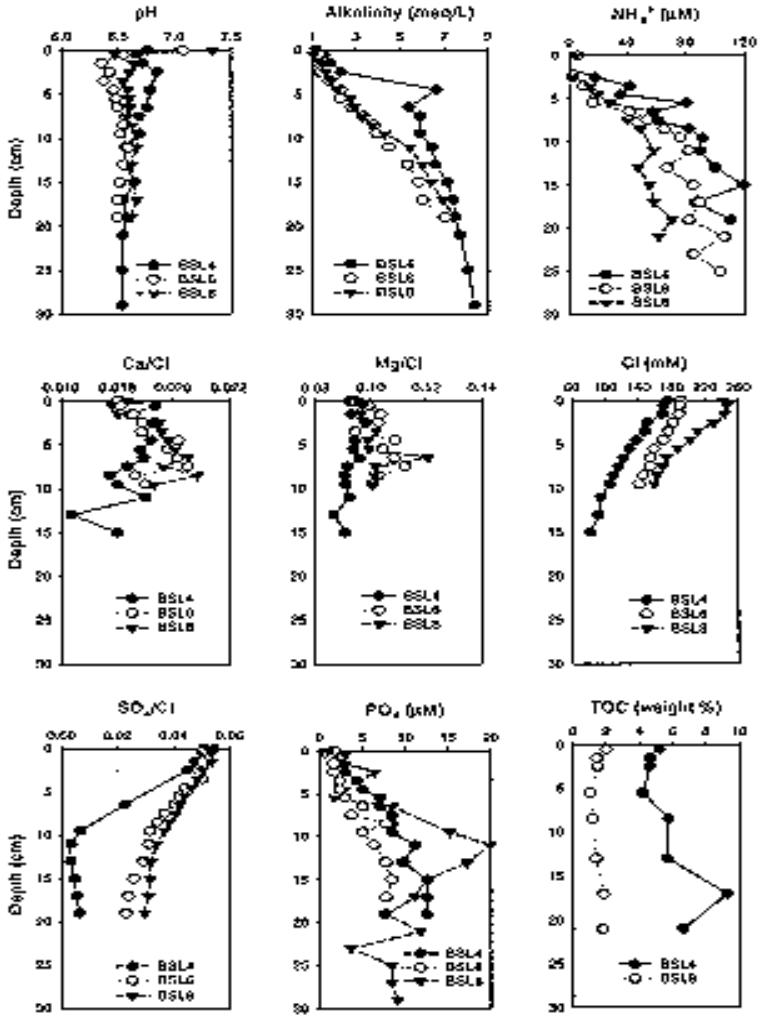

Figure 2. The depth profiles of pore water species measured at three separate locations within the Bay St. Louis study site.

IMPACT/APPLICATION

The Dry Tortugas study confirms the hypothesis that biologically-induced transport significantly affects the course of early diagenesis, and provides tools for the quantitative treatment of such transport. The tools include (1) characterization of biologically-determined sediment fabric (burrows), and (2) STEADYSED1 with the separate treatment of irrigation parameters. Because pore water irrigation is a predominant process in the reaction-transport regime of coastal sediments, it requires a separate attention during modeling. We expect that a separate attention to the biologically-induced particle transport, which will be pursued during FY99, will further enhance our ability to model early diagenesis.

TRANSITIONS

The irrigation treatment for STEADYSED1 developed by the Dry Tortugas study is now applied to study early diagenesis and biologically-induced transport in the Bay St. Louis study site. The forcing is determined by the integrated observations of pore water chemistry, sediment fabric, and benthic biology.

RELATED PROJECTS

Clay-organic matter (OM) association fabric in the Bay St. Louis sediments is being quantified using high resolution transmission electron microscopy (HRTEM) and energy filtered TEM (EFTEM). The presumed dependency of OM reactivity on OM morphology will be quantified. This project will help to improve the treatment of OM reactivity in reactive transport models.

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