Effects Of Sediment Microfabric on Benthic Optical Properties

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LONG-TERM GOALS

The overall goal of this project is to examine how inorganic factors, such as differences in sediment character or packing, contribute to the reflectance, scattering, and fluorescence of incident light at the seabed in coastal environments. Of particular interest is the degree to which the water column light field is sensitive to inorganic changes in bottom type, and whether such changes can be described in simple mathematical models. Ultimately, my intention is to apply this work to the identification of seabed sediment characteristics utilizing remote sensing platforms, such as hyperspectral satellite and airborne imagery. My secondary goal is to improve fiber-optic technology for standard use as probes to measure sediment parameters.

OBJECTIVES

Four hypotheses form the heart of my CoBOP objectives. They are 1) that the microfabric of grains at the sediment surface and to a depth of light penetration (~5 mm in well-sorted sands) has a strong impact on sediment reflectance and the in-sediment light field; 2) that the fluorescence of carbonate mineral grains is virtually universal in carbonate settings, and therefore, has a significant effect on sediment reflectance, while carbonate and other biogenic grains compose a smaller percentage of siliciclastic sediments and has an inconsequential impact on the overall benthic light signal; 3) that siliciclastic mineral fluorescence is present in 5-10% of the mineral grains in siliciclastic environments and is a useful tool for sediment provenance; and 4) that inorganic variations in grain size and composition are the first-order control on sediment reflectance and the in-sediment light field in bare sediments not covered by a significant algal mat or biofilm. In the latter areas, organic absorbance at specific wavelengths is a major contributor.

APPROACH

My approach for solving the four objectives outlined above has been two-fold. Objectives #1 and #4 have involved the development of a fiber-optic microprobe system that can be used to profile scalar irradiance from the sediment surface to the limit of light penetration in undisturbed sediment cores. The success of this methodology has yielded spectral information (350-1100 nm) from a variety of sediment settings. Core preservation methodologies have permitted preservation of original fabric for later impregnation and thin-sectioning to give quantitative information about inorganic properties of the sediments that are inducing changes in the light field. The methodology has also allowed for manipulation experiments to determine the relative impact of inorganic and organic sediment parameters. Core work is now transitioning into direct seabed measurements with the development of

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14. ABSTRACT **The overall goal of this project is to examine how inorganic factors, such as differences in sediment character or packing, contribute to the reflectance, scattering, and fluorescence of incident light at the seabed in coastal environments. Of particular interest is the degree to which the water column light field is sensitive to inorganic changes in bottom type, and whether such changes can be described in simple mathematical models. Ultimately, my intention is to apply this work to the identification of seabed sediment characteristics utilizing remote sensing platforms, such as hyperspectral satellite and airborne imagery. My secondary goal is to improve fiber-optic technology for standard use as probes to measure sediment parameters.**			
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new in situ probe technology by this study. Objectives #2 and #3 have been approached by using a microspectrofluorometer built into an epi-fluorescence microscope to generate and measure the spectral properties of sediments on a single-grain level. This has been supplemented by the use of a Fluoromax spectrophotometer to examine whole-sediment properties.

WORK COMPLETED

Field studies have been completed in league with other CoBOP PI's to Lee Stocking Island (LSI), Bahamas and Monterey Bay. LSI studies were conducted in May 1998, January 1999, and May, 1999, January 2000, May 2000, and April 2001. Monterey studies were conducted in April 1998, October 1998, and April 1999. Fiber-optic microprobe in-sediment light profiles have now been collected at all major sub-environments at each CoBOP field site in the two areas. Seasonal differences have also been measured at several of the key localities. All the 1998 and 1999 profile data has been submitted to the web-accessible CoBOP database.

Core material has been impregnated and over 100 thin-sections generated for cores analyzed by fiber-optic microprobe. Computer imaging software is being used to reduce information from each thin-section about downcore variations in porosity, grain size, shape factors, etc. All software results and the latest field results will be transmitted to the CoBOP website by year's end. Representative grain samples have also been collected and isolated for fluorescence studies at each of the major sub-environments at Monterey and LSI. Samples were also collected from representative beaches and nearby coastal environments to track source functions for the fluorescent particles. A suite of particle end members was analyzed by Fluoromax spectrofluorometer to determine the range of fluorescence observable at LSI. Detailed studies of the site grain fluorescence are ongoing with the newly upgraded epi-fluorescence microscope to do rapid spectral response fluorescence imaging with the addition of an Ocean Optics S2000 spectrophotometer.

In Year 4, a new planar fiber-optic probe was developed and tested at Lee Stocking that permits overhead core insertion in cores and can be deployed on the seafloor directly. This probe has greatly simplified and improved the measurements of light profiles and shows great promise as a tool for measuring a variety of sediment parameter in situ. This probe was utilized in the April 2001 field study to conduct an extensive study of mat vs. bare sediment areas and to analyze cores for diel changes in light penetration due to microbiota migration.

RESULTS

Our results to date from the fiber-optic microprobe work show that there is considerable variation in the downcore light field between sites. Work in earlier years of this study demonstrated that the light field variations can correspond to changes in the mineralogy or packing layers downcore. However, our studies of standard seived mixtures have shown that, within the limited grain size and shape variations present in the LSI and Monterey sites, the downcore light signal is relatively insensitive to changes in grain size and shape. Co-measurement of cores with Rob Wheatcroft's electrical resistivity probe in the April 2001 field study has shown that porosity plays the strongest role in light penetration (Fig. 1) variations between sites. In particular, the effect of biological mats produces a 20-80% increase in the depth of light penetration compared to bare sediments at the same site due to increased grain spacing (and possibly forward scattering) with growth of the mat (Fig. 1).

At many sites, the biological effects of absorbance by CDOM, biofilms, and benthic organisms (diatoms, etc.) overwhelm variations induced by inorganic differences in the sediment. This can be seen both in the increased porosity induced by surface mats and films and in the resulting profiles in cores where the biological component has been removed for comparison with the pre-treated light field. In addition, the PI and other CoBOP PI's (Decho, Reid, Wheatcroft, Voss) conducted a set of laboratory experiments in Miami in April 2001 to test the addition of EPS and other substances to quantify their effect on light penetration and other parameters. Presence of biofilm-like EPS substances significantly increased light penetration, supporting the field observations at LSI.

Epi-fluorescence microscope measurements in concert with David Burdige and Charlie Mazel have shown (Fig. 2) that the internal fluorescence in carbonate grains is broad and varies little between types of carbonates. This signature suggests that the signal is probably a result of humic organic matter trapped in the crystal matrix at the time of precipiation.

Limited diel studies of sediment cores in May 2000 showed that light penetration various diurnally with migration of benthic diatoms. This indicated that there will also be a concommitant change in bottom reflectivity as the upwelling component varies in the sediment. A more extensive dataset collected in April 2001 (Fig. 3) refutes this early data and supports the results of Larry Brand that diel variability in sediments has little or no effect on bottom reflectance or fluorescence.

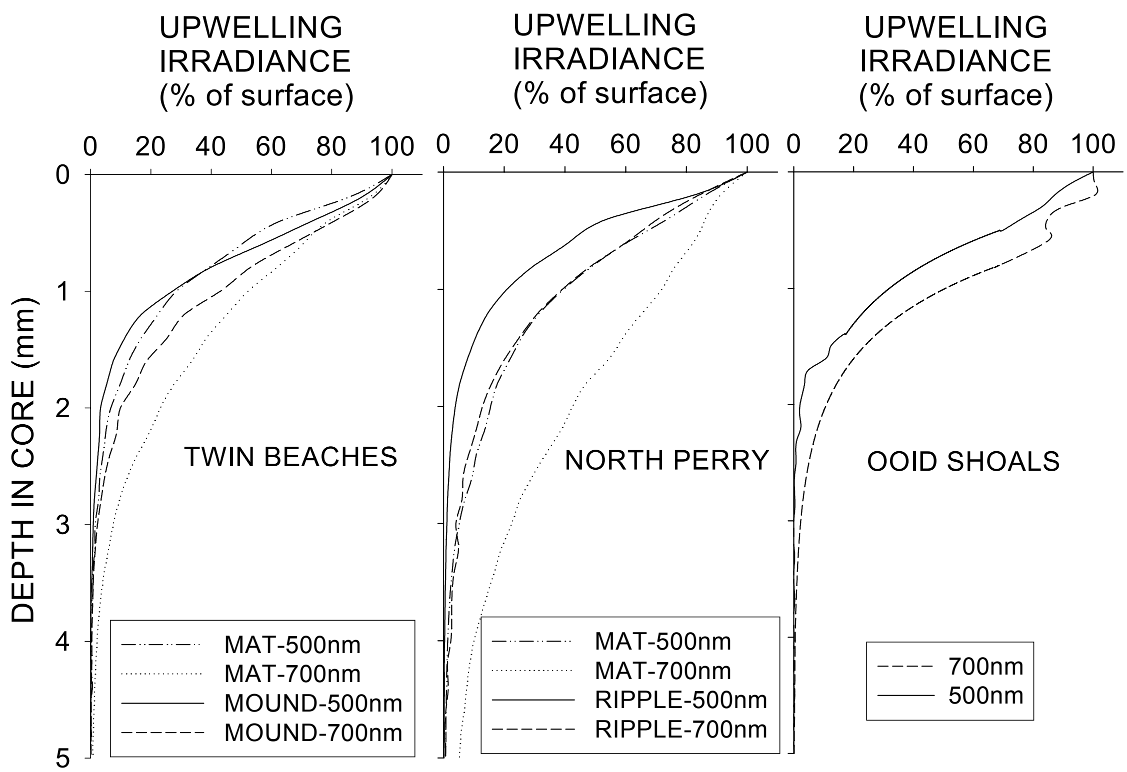

Figure 1. Plot of light penetration depth relative to levels measured at the sediment surface for all three study sites in April 2001 using the fiber-optic microprobes. Each plotted curve is an average of 3-6 measured profiles from a single core measured at 0.1 mm intervals downcore. In both sites where mats are found (North Perry and Twin Beaches), the depth of light penetration was greater than bare sands at the same wavelength. The bare sediment samples were collected from Callianassa mounds at Twin Beaches, and migrating ripples at North Perry and Ooid Shoals.

The new probe development has given opportunities for in situ work and for measuring in three different ways (Fig. 3): 1) an overhead light source to measure the sediment euphotic zone, 2) a self-illuminated fiber probe that allows examination of sediment fabric below the euphotic zone, and 3) a filtered self-illuminated (excitation) probe that permits measuring the intensity of biological fluorescence profiles in the sediment. Fig. 4 demostrates that the new self-illuminated design might also be a valuable probe for micron-scale measurements of sediment bulk properties in a variety of sediment types.

IMPACT/APPLICATION

Our fiber-optic microprobe work on sediment light fields is the first done on undisturbed marine sediments. It has shown that light fields can be easily modeled as a exponential decay downcore. This will permit variations induced by inorganic or organic structures in the sediment to be readily identifiable. The impact of this work raises the possibility of identifying sub-seafloor features solely from the reflectance spectra, given that our microprobe work has also shown that depth of penetration

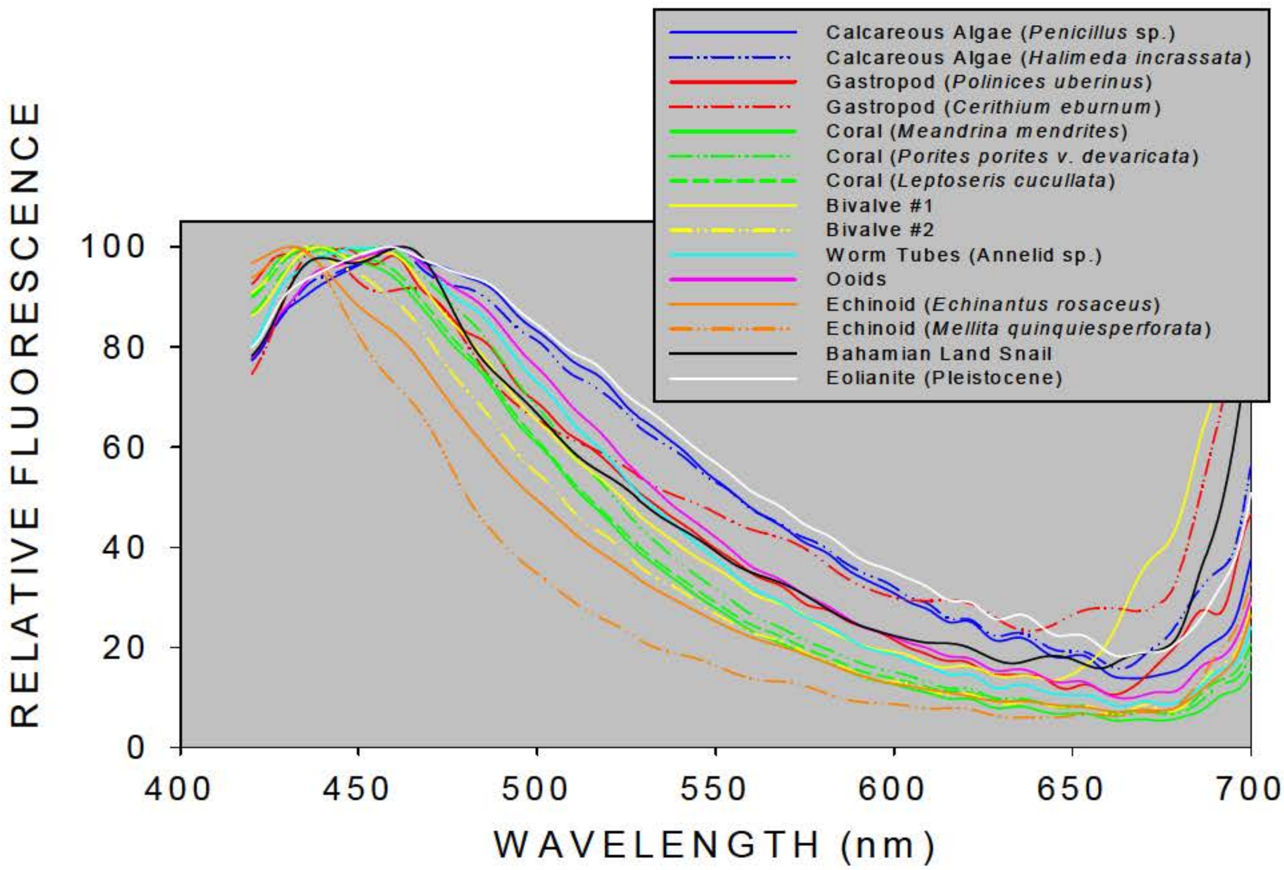

Figure 2. Fluorescence emission spectra of crushed and bleached endmember samples from LSI at excitation of 380 nm. These data demonstrate that the fluorescence inherent in the carbonate mineral structure is similar in different types of carbonates and is a broad, humic-like emission.

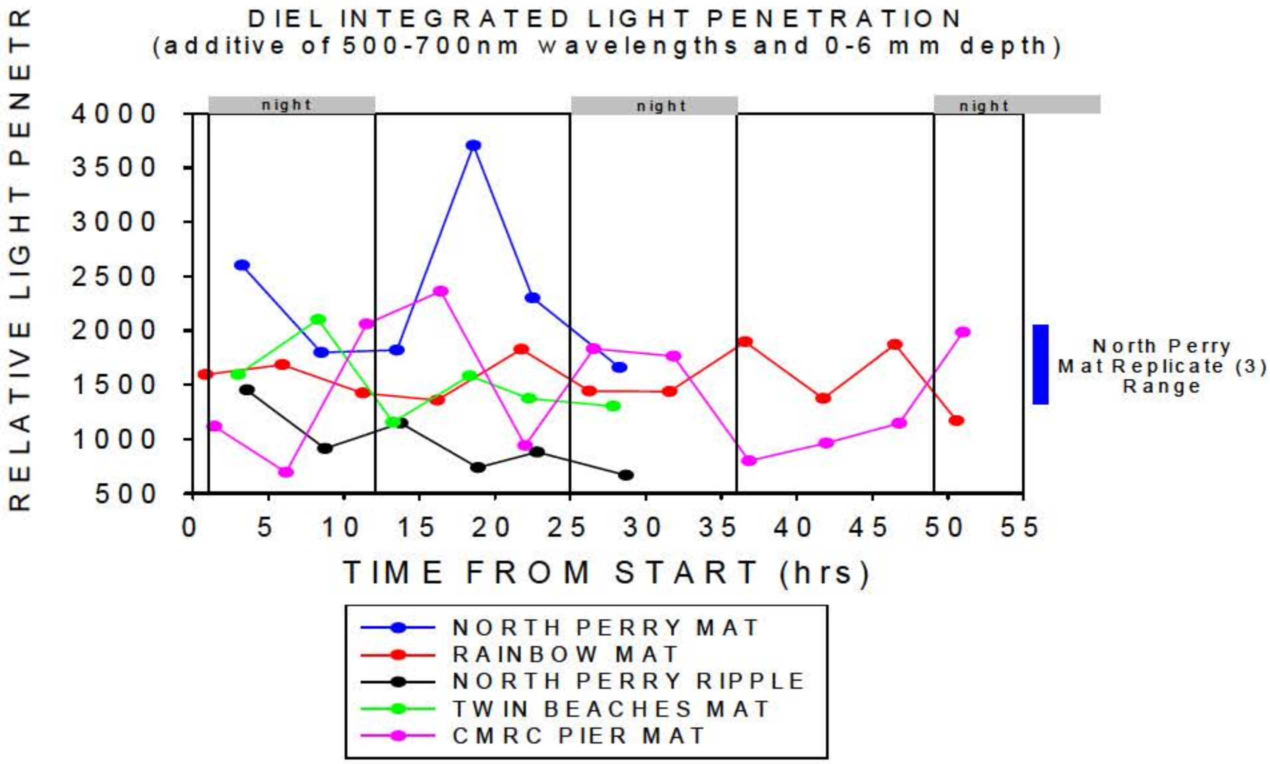

Figure 3. Diel studies of light penetration depth of sediment cores taken from biogenic mats at Lee Stocking Island and from control areas (ripples). Fiber-optic microprobe measurements were repeated every 4-5 hours and the cores incubated in outdoor tanks to simulate the natural environment. Data shows there is no trend of penetration with the day-night cycle and hence, diatom migration has a limited effect on changes in seabed reflectance and fluorescence.

of light is predictable dependent on wavelength (longer wavelengths penetrate further). In addition, this probe design can be used for rapid assessment of sediment properties in the seabed.

The grain fluorescence work to date has shown that it is the source of the apparent green background light visible in scans with laser line scanning systems at LSI. In siliciclastic sediment (Monterey), the mineral- and site-specific nature of fluorescence holds great promise as an indicator of sediment transport vectors in sandy sediments.

TRANSITIONS

I am investigating the use of fiber-optic microprobes as measurement of sediment bulk properties in near-seabed and seabed environments. The new in situ probe can measure bulk properties over enormous concentration ranges. This holds promise for developing a rapid seabed assessment probe for the navy. To pursue this avenue, a proposal has been funded byo ONR Geology and Geophysics for the new Mine Burial initiative. This experiment will allow testing of the probes for this purpose in league with other sediment assessment techniques (e.g., cone penetrometers, shear vane, electrical resistivity probes).

RELATED PROJECTS

1 – David Burdige (ODU), Charlie Mazel (PSICORP) and I are conducting a series of experiments on Lee Stocking Island carbonate grains to determine the organic (humic) substances that are present in the crystalline structure and whether they are the origin of the widespread broadband and week fluorescence noted in CoBOP studies of the area.

2 – I am working with the CoBOP sediment group (P. Reid, U. Miami, L. Brand, U. Miami, R. Wheatcroft (Oregon State), David Burdige (ODU), Fred Dobbs (ODU) and Alan Decho (U. South Carolina) in coordinating our sediment sampling of inorganic and organic parameters at the LSI and Monterey sites to determine the relative importance of our individual measurements in the benthic light signal. These measurements are being interfaced with reflectance measurements at the sites being made by C. Mazel (PSICORP), P. Reid (U. Miami), and Ken Voss (U. Miami).

3 – I am interacting with C. Stevens and L. Brand (U. Miami), P. Reid (U. Miami), and C. Mazel (PSICORP) in an effort to relate my measurements of in sediment light profiles to spectral reflectance data at the LSI sites to devise methodologies for deconvolving reflectance data to give information about the biological or inorganic changes occurring below the sediment surface. Diel measurements are mainly with Brand.

4- I am investigating the use of fluorescent siliciclastic sediment grains as a provenance tracer working with Brian Edwards and Steve Ettriem (USGS Menlo Park) in Monterey Bay, CA. We hope to establish the validity of this technique and to use it as a tool to determine sediment transport vectors as a means of tracing the dispersal of contaminated sediments in a USGS study of the the Monterey Bay and Gulf of the Farallons National Marine Sanctuary.

PUBLICATIONS

All publications in press, in prep or in the form of conference presentations.