

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

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parameters. Core work is now transitioning into direct seabed measurements with the development of 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.

The final years of the project have been focused upon data reduction, mining, and preparation of publications.

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 sieved 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 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.

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 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 precipitation.

Limited diel studies of sediment cores in May 2000 showed that light penetration varies diurnally with migration of benthic diatoms. This indicated that there will also be a concomitant change in bottom reflectivity as the upwelling component varies in the sediment. A more extensive dataset collected in April 2001 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.

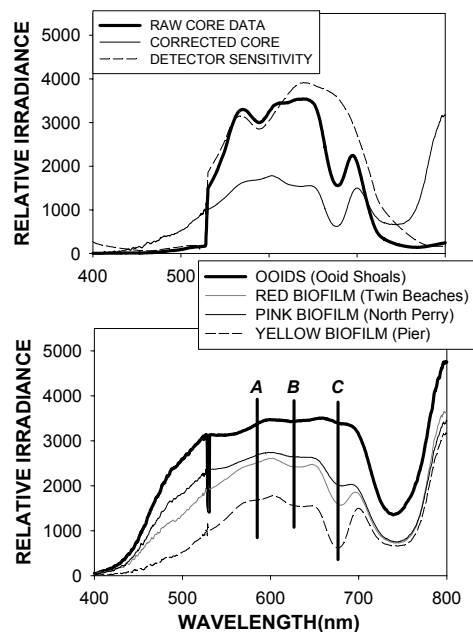


Figure 1. Relative downwelling irradiance four cores from LSI environments with variable biofilm density and type (ooids have none). Data is plotted to show raw spectral file at 0.5 mm depth and then the correction for fiber sensitivity (upper). Lower plot of the four cores at 0.5 mm depth in sediment shows differences in corrected light penetration and the presence in varying quantities of organic pigments that cause absorption at specific wavelengths. Pigment A is phycoerythrin, B is phycocyanin, and C is chlorophyll a. The large decrease in irradiance at ~750 nm is likely an instrumentation artifact. The sharp variations observed at about 530 nm are created by integrating the data from two fibers in the same microprobe each linked to a spectrometer with a diffraction grating blazed to receive a different wavelength band.

The new probe development has given opportunities for in situ work and for measuring in three different ways: 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. 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.

The final year's efforts were focused on "data mining", particularly of the use of microprobe spectral data of variations with depth that are attributable to changing phytobenthic community and abundance (Fig. 1). Deconvolution methods were utilized to identify a variety of pigments (chlorophyll *b* and *c*, phycoerythrin, phycocyanin, fucoxanthin, peridinin, and zeaxanthin). It was demonstrated that this methodology has great promise, when calibrated with real values of pigment concentration (HPLC, etc.) for subsurface mapping of phytobenthic communities. Efforts were also focused on preparation of manuscripts for publication.

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 an 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 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 has been completed in September 2003 using funds from an ONR DURIP program. The sediment insertion mechanism and memory storage for the spectral files was fabricated with the Oceanography Shop at University of Washington. The new system can measure bulk properties over enormous concentration ranges. This holds for developing a rapid seabed assessment probe for the navy. To pursue this avenue, a proposal has been submitted to ONR Coastal Geosciences to field test the in situ probes for a study of hyperpycnal sediment transport on the Mississippi-Atchafalaya deltaic shelf.

The in situ probe tripod is also capable of detailed study of biogenic degradation of bedforms by microphytobenthic communities using the spectral depth mapping methodology mentioned above. A proposal will be submitted in Fall 2003 to examine this issue as part of the ONR SAX DRI designed to measure and model the behavior of sandy bedforms in coastal environments, including the effects of biological stabilization and degradation of seabed surfaces.

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 weak 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 Ettrien (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

Allison, M.A. and Taylor, B.B. Effects of sediment microfabric on the in-sediment light field in sandy coastal settings. *Limnology and Oceanography*. [in press, refereed]

Allison, M.A. and Robb, B.W. Use of mineral fluorescence as a tracer of sand transport vector: an examination of Monterey Bay, CA. *Journal of Sedimentary Research*. [submitted, refereed]

Decho, A., Kawaguchi, T., Allison, M.A., Louchard, E., Stephens, C., Reid, P., Voss, K., Wheatcroft, R., and Taylor, B.B. 2003. Sediment properties influencing up-welling spectral reflectance signatures: the "biofilm gel effect". *Limnology and Oceanography* 48:431-443. [published, refereed]

PATENTS

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