

# **Composition, Texture and Diagenesis of Carbonate Sediments: Effects on Benthic Optical Properties**

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## **LONG-TERM GOAL**

Our long-range objective is to understand how physical, chemical and biological characteristics of bottom sediment affect the optical properties of the shallow sea floor. Of particular interest is the identification of sedimentological parameters that can be resolved using optical methods of remote sensing. Our research focuses on carbonate sediments.

## **OBJECTIVES**

Specific objectives are: (1) to establish correlations between compositional and textural (e.g. size, shape, surface roughness, density, and packing) parameters, benthic microbial communities, and spectral reflectance; and (2) to define optically distinct sediment types based on sediment reflectance and water-leaving radiance from spectral radiometer buoys and aircraft sensors. This work is part of ONR's program on Coastal Benthic Optical Properties (CoBOP).

## **APPROACH**

During the past six years, we have studied the optical properties of shallow marine carbonate sediments in the vicinity of Lee Stocking Island (LSI), Bahamas. We have been involved in successful field campaigns at LSI in May 1998, May 1999, May 2000, June 2001, July 2002 and August 2003. Results to date, which are being integrated with studies by a variety of other CoBOP investigators, include sedimentological analyses, spectral reflectance of sediment cores, and hyperspectral tethered spectral radiometer buoy (HTSRB) measurements.

During the past year, our research focused on improving methods of recovering bottom reflectance from remotely sensed hyperspectral signals. This work was conducted by PhD student Eric Louchard (now at Science and Technology International Industries), under the supervision of R.P. Reid and in collaboration with Curt Mobley (Sequoia Scientific Inc.). A new PhD student, Daniel Doolittle, will continue to work on the project this fall (funding period is Dec. 1 2002-Nov. 30, 2003). Our primary task was to remove water column attenuation from hyperspectral remote sensing imagery in shallow waters. The goal of water column removal was to acquire a map of bottom reflectance, which could

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then be spectrally classified to distinguish bottom types. A simple exponential method derived from Beer's Law was used first to determine the general effectiveness of the approach. Results from the simple method were then compared with a second, more robust method of water column correction, which utilizes radiative transfer in "Hydrolight 4.2" (Sequoia Scientific Inc.). Results to date are summarized below.

#### *Water column Removal Method 1:*

Attenuation effects of the water column were removed from hyperspectral imagery using a simple exponential equation to calculate bottom reflectance ( $R_b$ ) in dimensionless units. The equation was based upon Beer's Law and existing work by Maritorena and Morel (1994) but included additional parameters that estimate the effects of transmission of downwelling irradiance (0.97 of  $E_d$ ) and upwelling radiance (0.54 of  $L_u$ ) across the sea surface interface. The following equation was applied to each pixel of the image in the program Matlab 6.5 (The Mathworks, Inc.).

$$R_b = R_\infty + ((R_{rs} - R_\infty)(\pi/(0.97*0.54)))e^{(z*kd)}e^{(z*ku)} \quad (1)$$

Remote Sensing Reflectance ( $R_{rs}$ ) data were collected in the "Adderly Cut" area of Lee Stocking Island using the airborne PHILLS (Portable Hyperspectral Imager for Low Light Spectroscopy) sensor on 01 June 1999 (Davis et al. 1999, 2002). The spectrum of infinitely deep water ( $R_{inf}$ ), and diffuse attenuation coefficients  $k_u$  and  $k_d$  were modeled using Hydrolight 4.2. Inputs to Hydrolight included water inherent optical properties (IOP's) measured using a WET Labs ac9 (WET Labs Inc. Philomath, OR) following the methods of Twardowski et al. 1999. Water depth ( $z$ ) at each pixel was taken from a bathymetric map of Adderly Cut created through a comparative spectral library approach (Louchard et al. 2003).

The resulting bottom reflectance map was classified through an unsupervised Isodata approach in the program ENVI 3.4 (RSI Inc.) to separate distinct bottom features on the basis of spectral shape and magnitude. Bottom classes were matched with ground-truth observations from underwater video recordings. Video data were collected in June 2001 in the Adderly Cut area with a Sony DCR-TRV900 digital camera housed in an Aqua Video case and mounted on a pole attached to the gunnel of a small boat.

#### *Water column Removal Method 2:*

Bottom reflectance spectra recovered using Method 1 were compared to results obtained using a more robust radiative transfer method.  $R_r$  spectra were selected from the PHILLS imagery and run through the program "Ecolight-WCC", a modified version of "Hydrolight", developed by C. Mobley specifically for 'Water Column Correction'. Ecolight-WCC removes water column effects through an iterative process, guessing an input bottom reflectance and solving the radiative transfer equation multiple times until the simulated  $R_{rs}$  results match with measured  $R_{rs}$ .

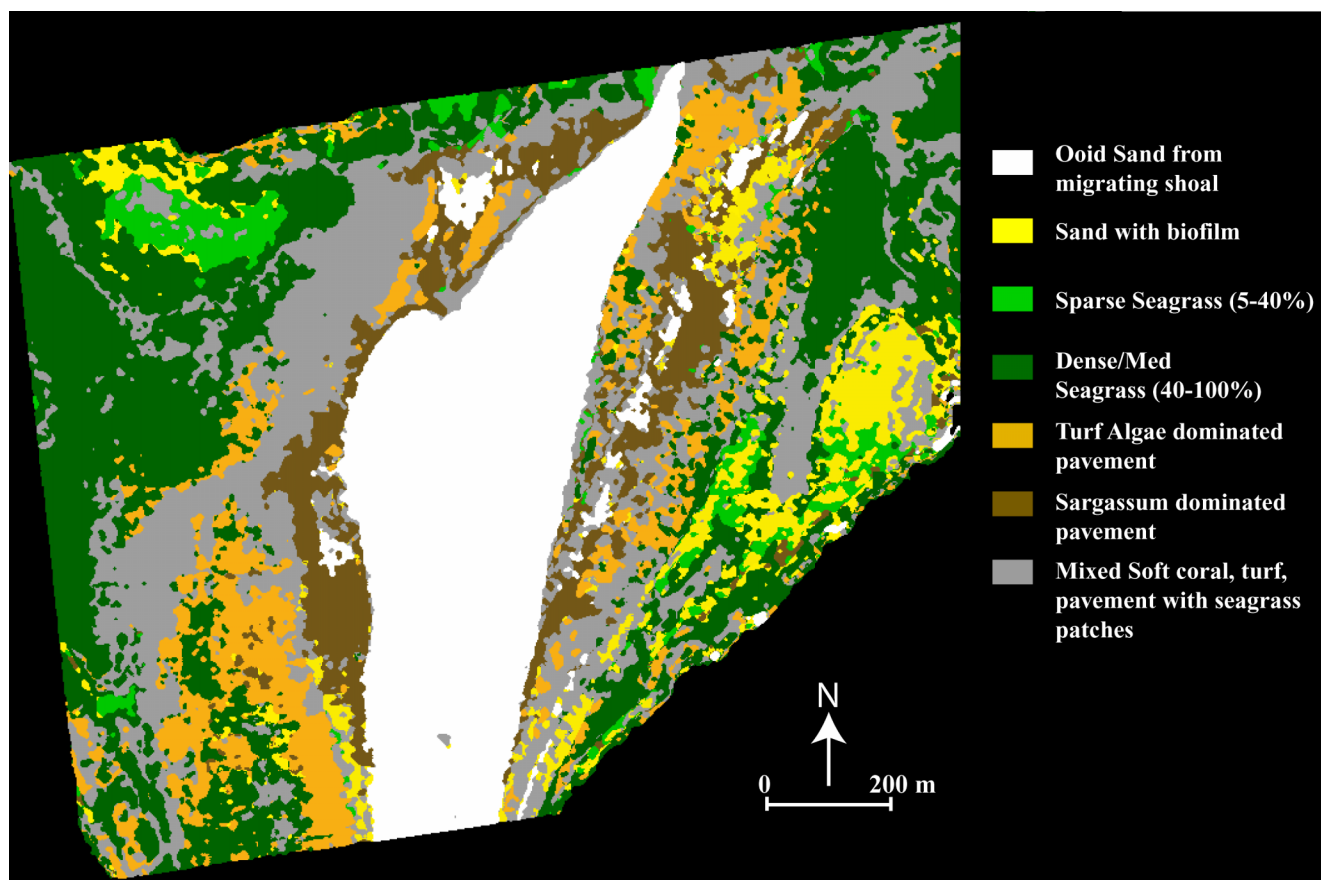
Reflectance was recovered from PHILLS spectra collected at three areas with known depth, water properties, and bottom type. Sediments from Channel Marker, Rainbow South, and Twin Beaches were chosen as representative bottom types. Bottom reflectance spectra recovered by Method 1 and Method 2 were compared to measurements of sediment core reflectance collected from May 24 to

June 01 1999. Core reflectance spectra were measured using a S2000 spectrometer following the technique of Louchard et al. (2003).

## WORK COMPLETED

*Water Column Removal Method 1:* Bottom reflectance was recovered for each pixel in the hyperspectral image. Wavelength spectra were restricted to the range 400-570, the region in which data contained sufficient signal to recover reflectance at all depths in the imagery. Unsupervised classification of the image produced fifteen distinct bottom classes, which were matched by GPS position to video bottom types in one half of the video data. Data matching produced three major classes (sand, seagrass, and pavement) and seven subclasses (Fig. 1). Accuracy was measured by comparing the data classes to the second half of video. These determinations showed an overall accuracy of 89% for major classes and 79% for subclasses. All major classes were equally accurate but the highest accuracy for subclasses was found in sand (94% producers, 84% users). The lowest accuracy was in sargassum-dominated pavement (59% producers, 65% users).

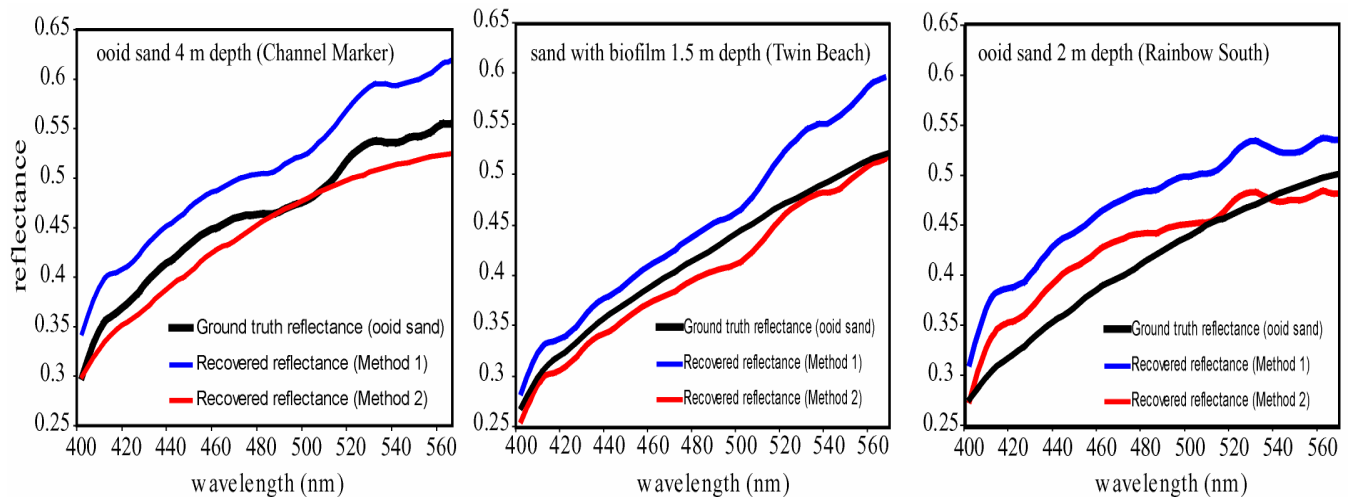
A possible cause for this inaccuracy is the low overall density of soft corals and sargassum on the bottom, even when they are the dominant cover. The high percentage of bare pavement, light in color, causes the seafloor to appear similar to other pavement bottoms such as turf algae and soft coral/turf.



*Figure 2. Bottom classification after water column removal.*

Water Column Removal Method 2: Bottom reflectance recovered from PHILLS data using Ecolight-WCC was found to be more accurate than the simple algorithm from Method 1. Even in the clear waters of Lee Stocking Island, where backscatter is negligible, Method 2 produced a closer match in magnitude to ground truth reflectance of sand when compared to the Method 1 (Fig.2). Differences in spectral shape for both methods compared to ground truth were primarily related to errors in  $a_{c9}$  absorption and beam attenuation measurements.

Ecolight-WCC has, to date, been used to recover bottom reflectance from selected PHILLS spectra but not from an entire PHILLS image as procedures for handling large datasets required optimization. Those procedures have recently been completed and we are currently analyzing imagery for comparison with maps created using the simple Beer's Law method.



**Figure 2. Recovery of sediment bottom reflectance using Method 1 (Algorithm derived from Beer's Law) and Method 2 (Ecolight-WCC). Examples are shown from three different areas.**

## RESULTS

Results from our study are being made available to other members of the CoBOP team via an FTP site at RSMAS. Major findings of the work completed during the past year are as follows:

1. A simple algorithm derived from Beer's law was found to be effective in recovering bottom reflectance spectra from hyperspectral PHILLS imagery. The image could then be analyzed using an unsupervised routine which, without water column correction, would classify strictly by depth. Results of classification were accurate (89% for sand, seagrass and pavement) when compared to ground truth observations.
2. Bottom reflectance spectra recovered from PHILLS imagery using Ecolight-WCC software were more accurate than those recovered using the simple algorithm method. Differences in results using the two methods were relatively small in the clear waters around Lee Stocking Is. However, in regions with higher backscatter, such as turbid areas, differences between the two methods will be greater. Analysis of PHILLS imagery has, to date, been limited to individual spectra or groups of spectra but analysis of entire PHILLS images is presently underway. We also plan to continue collaboration with Curt Mobley to develop a more efficient version of Ecolight-WCC, which can process PHILLS images rapidly, to retrieve bottom reflectance on a pixel-by-pixel basis in hours rather than days!

## **IMPACT/APPLICATION**

Our results indicate that significant loss in magnitude and shape of bottom reflectance spectra results from propagation through the water column. This loss limits accurate bottom classification of remotely sensed spectra. Removal of water column effects improves bottom classification by recovering both shape and magnitude spectral information. Analytical tools typically used in terrestrial environments, such as unsupervised spectral classification, can then be used to classify benthic habitats

## **RELATED PROJECTS**

Our work is closely related to projects of several CoBOP investigators. We collaborated with Carol Stephens (RSMAS) to quantify relationships between spectral reflectance and pigment concentrations (Stephens et al. 2003). Measurements to determine the effects of polymer on sediment reflectance were made in collaboration with Alan Decho (U. South Carolina; Decho et al. 2003). Ken Voss (U. Miami) is using our grain size data to model bi-directional reflectance distribution function (Zhang et al. 2003). We continue to work with Curt Davis and others at NRL and Curt Mobley on analysis of PHILLS data. Results of our research are also incorporated in our ongoing work on integrated optical and acoustic seafloor classification (N000140110671, this volume).

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