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 five 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, and July 2002. 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 determining effects of water column attenuation on remotely sensed signals, and finding ways to recover the maximum information regarding sediment types from hyperspectral signals collected at the sea surface. Our first task was to use derivative spectroscopy to analyze bottom reflectance collected at variable distances from the seabed. The second task was to recover true bottom reflectance from surface HTSRB measurements of L_u/E_d and to use spectral analysis tools to classify recovered signals based on spectral shape. Methods are summarized below.

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14. ABSTRACT
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15. SUBJECT TERMS

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Derivative analysis: Bottom reflectance was analyzed from seven carbonate sediment types (Fig. 1), categorized into three groups depending on the amount of microalgal film present: minimal microalgal film (Sediment Types 1,2,3); moderate microalgal film (Sediment Types 4,5,6); dense brown colored algal layer (Sediment Type 7). HPLC pigment analysis of these sediments identified Chlorophyll *a* and *b*, and accessory xanthophills (fucoxanthin, peridinin) and carotenes (zeaxanthin, lutein, *B*-carotene) (Stephens et al. in press).

Reflectance was measured at the seabed, at the sea surface, and at an airborne PHILLS (Portable Hyperspectral Imager for Low Light Spectroscopy) sensor. Seabed measurements were made on sediment cores, collected from 24 May to 01 June 1999, using a S2000 spectrometer following the technique of Louchard et al. (in press). Sea surface measurements of L_u/E_d were collected with a HTSRB deployed between 24 May to 01 June 1999 at the same GPS positions as the sediment cores. Hyperspectral PHILLS spectra were taken from an image of LSI captured on 01 June 1999 (Davis et al. 1999, 2002), georeferenced using ground control points from IKONOS data.

Derivative analysis of hyperspectral reflectance spectra proceeded using finite approximation to calculate the change in reflectance over a bandwidth $\Delta\lambda$, defined as $\Delta\lambda = \lambda_j - \lambda_I$, where $\lambda_j > \lambda_I$ (Tsai and Philpot, 1998). Peaks in the derivative spectra were distinguished from spectrometer noise using the method of Huguenin and Jones (1986).

Recovery of Bottom Reflectance: Hyperspectral TSRB remote sensing data collected at LSI from 16-20 June 2001 were used to recover bottom reflectance. HTSRB measurements of L_u/E_d were collected by towing the instrument 20 m behind the boat at 4-5 knots. Additional data collected included:

1. Inherent optical properties of the water (IOP's), measured using a WET Labs *ac*9 (WET Labs Inc. Philomath, OR) following the methods of Twardowski et al. 1999.
2. Underwater video recordings, made using a Sony DCR-TRV900 digital video camera housed in an Aqua Video case and mounted on a pole attached to the gunnel of the boat.
3. Bathymetry, measured using a Suzuki ES2025 echo sounder with a 50 kHz transducer.
4. Positioning, tracked using DGPS with a Wide Area Augmentation System (WAAS).

Water column attenuation was removed from measurements of L_u/E_d through the use of the program "AO Ecolight", a modified version of "Hydrolight" (Sequoia Scientific Inc., Redmond, WA). AO Ecolight removes water column effects through an iterative process, guessing an input bottom reflectance and solving the radiative transfer equation multiple times until the simulated L_u/E_d results match with measured L_u/E_d. The magnitude of the change in reflectance at each wavelength depends on the ratio of AO Ecolight output L_u/E_d verses measured TSRB L_u/E_d.

Reflectance spectra retrieved from the TSRB, after water column removal, were separated into distinct groups using principal components analysis (PCA) to identify distinguishing features in their spectral shapes and differences in spectral magnitude. The software used for PCA was QTC IMPACT (Quester Tangent Inc.), a package designed originally for analysis of acoustic spectra.

WORK COMPLETED

Derivative analysis: Comparisons of reflectance measurements made at the seabed with remote sensing signals collected at the sea surface (TSRB) and in the atmosphere (PHILLS) (Fig. 1A) showed significant effects of water column attenuation. Signal loss occurred over the entire spectrum, reducing overall magnitude, with the greatest losses past 600 nm. Spectral shapes of PHILLS remote sensing reflectance spectra (R_{rs}) were similar to L_u/E_d spectra from the TSRB, but the higher spatial resolution PHILLS data retained more small-scale absorption features below 600 nm, such as the dip at 550 nm in Sediment Types 1 and 5.

Derivative analysis was successful in enhancing small absorption features in all reflectance spectra, thereby facilitating identification of sediment pigments (Fig.1B). S2000 derivative spectra showed 12 sharp peaks relating to chlorophyll *a* and accessory pigments (Stephens et al in press). Derivative analysis of R_{rs} and L_u/E_d showed that many of the pigment absorption peaks found in S2000 spectra were lost during transmission of the reflectance signal through the water column. TRSB spectra showed only seven major absorption features, with two of the most prominent peaks (545-555 nm and 595-605 nm) corresponding to water absorption. PHILLS derivative spectra were similar in shape to TSRB spectra but showed stronger absorption features in the 400-500 nm range and a greater number of absorption features from 550–650 nm (9). In both the TSRB and PHILLS data, the only pigments that could be identified in derivative spectra were chlorophyll *a* and a mixture of fucoxanthin and peridinin.

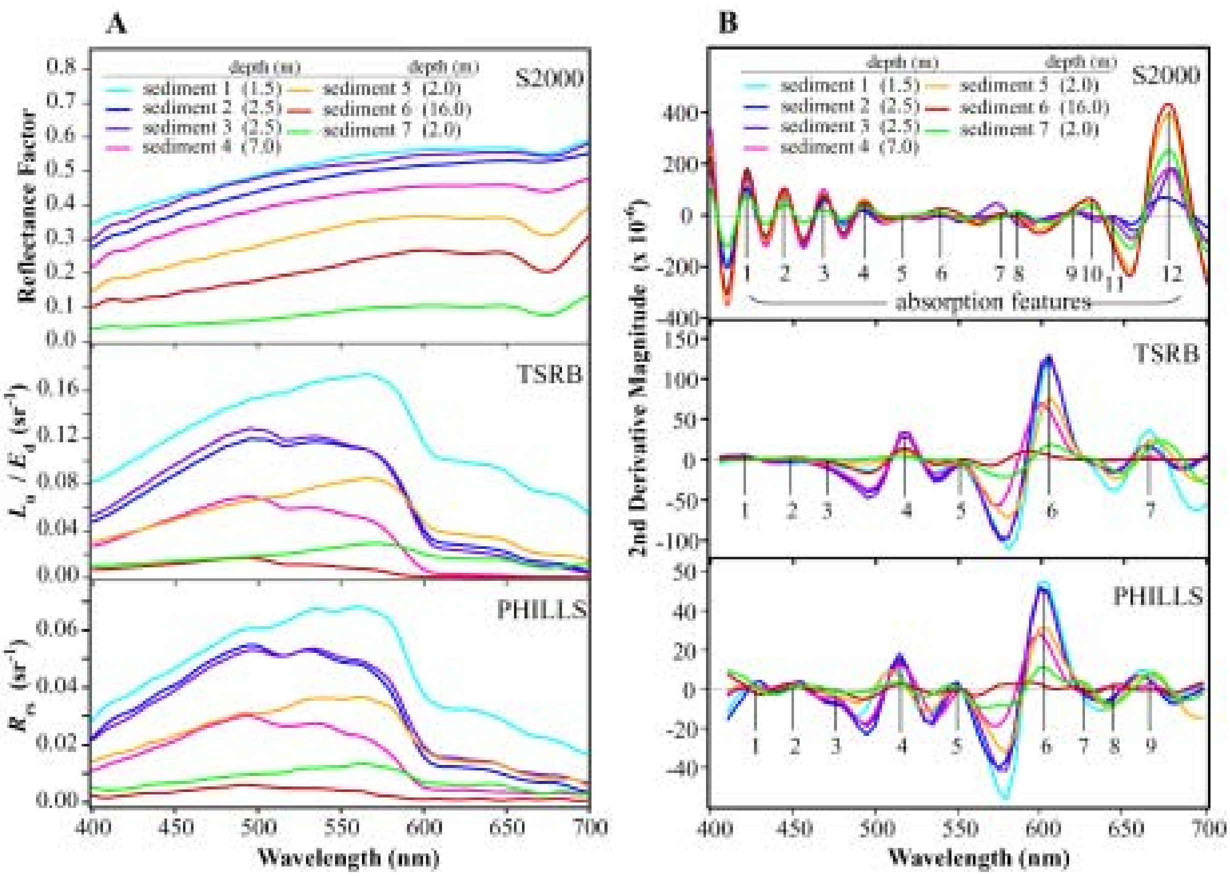

Figure 1. Bottom reflectance and derivative analysis of absorption features. (A) Comparison of bottom reflectance measured with an S2000, TSRB, and PHILLS. Water attenuation is most apparent past 600 nm. (B) Second derivative of bottom reflectance from an S2000, TSRB, and PHILLS. Absorption features are numbered and correspond to derivative peaks.

In addition to enhancing absorption features, derivative analyses of R_{rs} and L_u/E_d spectra can also be used to estimate bathymetry in shallow regions. A high correlation was found between the ratio of the 2nd derivative peaks at 605 nm and 515 nm and water depth (TSRB $R^2 = 0.9617$, PHILLS $R^2 = 0.9213$). The absorption peak at 605 nm in the derivative spectra is caused by water attenuation. Alone, this peak shows poor correlation with water depth (TSRB $R^2 = 0.5806$, PHILLS $R^2 = 0.5706$), as absorption from microalgal pigments and scattering from polymer microfilms reduce overall reflectance magnitude (Decho et al. 2002). Use of the ratio of the 605 nm peak relative to the 515 nm peak, which is related to fucoxanthin absorption, removes much of the variability in magnitude caused by pigments and polymer microfilms and significantly improves the correlation.

Recovery of Bottom Reflectance: Bottom reflectance was extracted successfully from 22143 measurements of Lu/Ed from the TSRB. Reflectance spectra were grouped into 17 spectral clusters, which were then matched by GPS position to video bottom types in half of the video data. Data matching produced three major classes (sand, seagrass, and pavement, Fig.2A) and five subclasses (Fig. 2B). Accuracy was measured by comparing the TSRB classes to the second half of video. These determinations showed an overall accuracy of 81% for major classes and 70% for subclasses, with some mismatches in patchy bottoms or at borders between different bottom types.

Much of the error in TSRB classification appears to be associated with the large field of view of the sensor (8.5° half angle): diverse bottom types within the large field of view of the TSRB will be integrated into an amalgam spectrum. Evidence for this comes from scuba observations in July 2002, which documented pavement bottoms interspersed with seagrass patches, especially near the edges of the eastern side of the ooid shoal. Similarly, seagrass varied in density throughout the seagrass beds, causing the TSRB to blend the densities into a single (10-70%) class.

Results from our study are being made available to other members of the CoBOP team via an FTP site at RSMAS; they have not been submitted to a national archive.

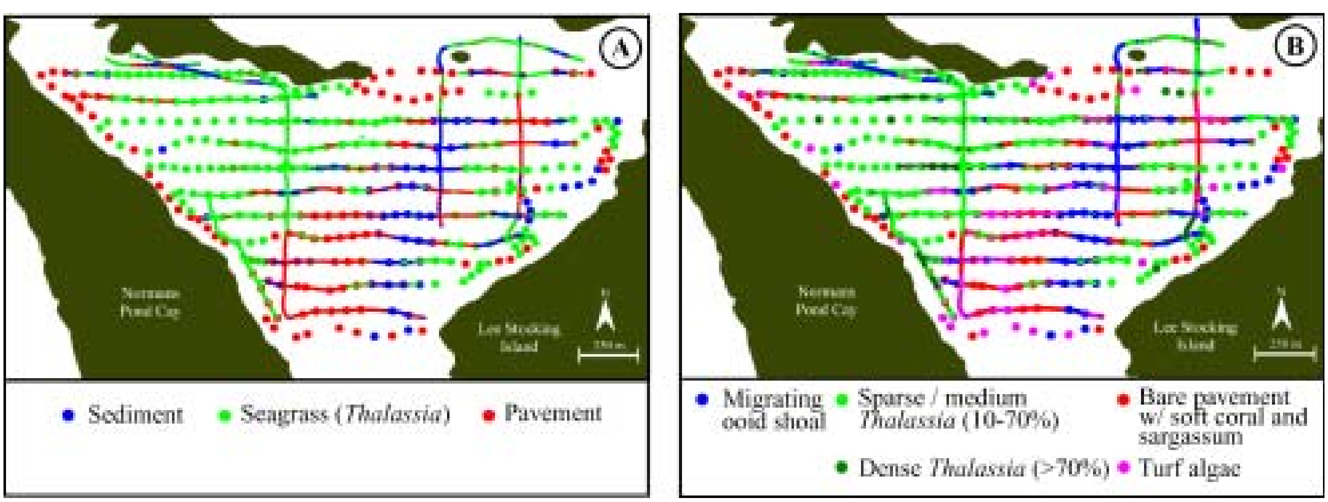

Figure 2. Bottom class from TSRB (lines) and video (dots). A) Major classes B) Subclasses

RESULTS

Major findings of the work completed during the past year are as follows:

1. Derivative analysis of remote sensing reflectance spectra from TSRB and airborne hyperspectral sensors was effective at enhancing absorption features caused by pigments in bottom sediment. However, water column attenuation removed absorption features from pigments other than chlorophyll *a* and fucoxanthin/peridinin. Absorption peaks from water and pigments were combined to estimate bathymetry.

2. Bottom reflectance spectra were successfully recovered from TSRB L_u/E_d measurements using AO/Ecolight. Recovered spectra contained sufficient spectral shape and magnitude information for effective classification of bottom types.

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 prohibits accurate bottom classification. Removal of water column affects improves bottom classification by recovering both shape and magnitude information. The application of terrestrial analysis tools, such as derivative spectroscopy, can then be applied to identify absorption features.

TRANSITIONS

Recovery of bottom reflectance, as developed in this project, is being used in development of opti-acoustic seabed classification (Reid this volume, Award N000140110671). Continued collaboration with Curt Mobley in this area will develop a new version of AO Ecolight that can process PHILLS images on a pixel-by-pixel basis to retrieve bottom reflectance.

RELATED PROJECTS

Our work is closely related to projects of several CoBOP investigators. Carol Stephens (RSMAS) is collaborating with us to quantify relationships between spectral reflectance and pigment concentrations (Stephens et al. in press). Measurements to determine the effects of polymer on sediment reflectance were made in collaboration with Alan Decho (U. South Carolina; Decho et al. in press). Ken Voss (U. Miami) is using our grain size data to model bi-directional reflectance distribution function (Zhang et al. in press). We are working with Curt Davis and others at NRL on analysis of PHILLS data (Louchard et al. in press).

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