Spectral Analyses and Sedimentation of the West Coast Beaches of Puerto Rico

Undergraduate Research Final Report
by:

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ABSTRACT

Remote sensing techniques were used to correlate spectral measurements as the reflectance (object’s radiance divided by the irradiance) to the sediment characteristics such as grain size, sand composition, and mineralogy along the west coast of Puerto Rico. These sand sediments were sampled at different geologic conditions, Punta Algarrobo and Punta Guanajibo, which are affected by continuously sediment discharge, and Punta Ensenada and Playa Azul (Punta Arenas), which are not. The spectral variability was determined using the GER - 1500, and the sediments characteristics were tested using the sieving method, the XRD, and % of carbonate. Field data indicates that reflectance intensity changes during variation of carbonate material. The reflectance spectral ratios were determined and used to correlate mineral composition of sand to sediment properties throughout stations. Preliminary associations of remote sensing reflectance (Rrs), to sand patterns were obtained. Also, this study provides another important step for better applications of remote sensing in the western coast of Puerto Rico.

INTRODUCTION

Research based on the grain size, composition and mineralogy of the different beaches of the west coast of Puerto Rico has been made during the past decades, but never related to the spectral signature of those sediments (Barreto, 1997). Satellite data, when calibrated and compared with “in situ” observations, can provide detailed information on sediments transport by rivers discharge as shown using LANDSAT- MSS (Multi Spectral Scanner) AND AVHRR (Advanced Very High Resolution Radiometer) reflectance data in Chesapeake Bay (Stumpf, 1988).
Remote sensing is the science of deriving information about an object without actually coming in contact with it. The quantity most frequently measured by current remote sensors is the electromagnetic energy reflected or emitted by the object of interest. Most remote sensors are located in platforms (satellites, airplanes, boats, etc.), but several can be used from hand as the GER-1500 spectroradiometer who measures the reflectance of the body. This investigation will correlate the reflectance from the GER – 1500, known as the radiance of an object divided by the irradiance, with the sediment characteristics such as grain size, sand composition, and mineralogy along the west coast of Puerto Rico.

Puerto Rico is the smallest island of the Major Antilles located at the Caribbean Sea. Its west coast is located around 18° N and 18° 30’ N, and 67° 10’ W and 67° 14’ W. This area is highly influenced by three river systems, the Río Grande de Añasco (nutrients mainly from agriculture and sewages), Río Yagüez, and Río Guanajibo, and by anthropogenic activities, like the sewer outfall (nutrients from sewages) and the tuna factory (Morelock, 2002). The geology of the west coast is also very different within it (Figure 1); composed of rocks and sediments of the Post- Eocene, sediments and igneous rocks from the Eocene, rocks from the Cretacic, and serpentinite, chert, amphibolites, and alkaline rocks.

Several studies have related the sedimentation and coastal changes of Puerto Rico. But few of them have used the techniques applied in this research. One of these studies was the “Shoreline changes in Puerto Rico: (1936-1993)” (Barreto, 1997). This study was based on the variation and/or pattern changes of the Puerto Rico shoreline. Another research was the “Characterization of sediment influx and hard coral cover analyses of Boquerón and La Parguera, Puerto Rico” (Morelock, 1998). The major purpose of this project was to correlate coral cover and sediment inputs. However the application of
remote sensing techniques on these beaches sediments, as the reflectance variability, still not be done. As was mention, the main purpose of this undergraduate research is to correlate the spectral signature (reflectance) of the west coast beaches of Puerto Rico with sedimentation analyses, such as grain size, composition and mineralogy. In order to accomplish this goal the specific objectives are:

1. Determine the spectral variability of different beaches in the west coast of Puerto Rico.
2. Determine the changes and/or types of grain size, composition, and mineralogy at the different beaches.
3. Provide recommendation for future applications of remote sensing using satellites and/or airplane sensors.

Figure 1: Geologic map of Puerto Rico.

METHODOLOGY

Field Work:

Four study sites in the west coast of Puerto Rico were selected based on geographical location and geologic conditions (Figure 2). Two of them are highly
affected by sediments discharge from the river systems and the other two are not. The accesses to different geologic and sedimentation environments were also considered. The study sites were Punta Ensenada, Punta Algarrobo, Punta Guanajibo, and Playa Azul. Punta Algarrobo and Punta Guanajibo are affected by sediment discharge from the Río Grande de Añasco, Río Yagüez, and Río Guanajibo and by the dumping of the tuna factory (Figure 2). In the other hand Punta Ensenada and Playa Arenas) were used as control to evaluate different exposition to sediment stress, nutrients and organic material.

![Figure 2: Location of sampling sites in the western Puerto Rico. The bottom left corner shows a False Color Image of LANDSAT-Thematic Mapper demonstrating the study sites and rivers between them.](image)

The four stations were sampled at three backshore transects on the west coast of Puerto Rico extending from Rincón to Cabo Rojo. At each station, samples were taken from the surface at distances of 12 meters to each other; also all the stations were registered using GPS positions to be located in a satellite image (Appendix 1).
The GER – 1500 spectroradiometer was used to measure the reflectance of each station. The equation used was:

\[
R_{rs} = \frac{\text{Object Radiance}}{\text{Irradiance}}
\]

\[
R_{rs} = \frac{L}{E_d}
\]

For better description of each beach digital pictures of the sampling area were taken (Appendix 2).

**Laboratory Work:**

The laboratory work was performed at the Geology Department of the University of Puerto Rico, Mayagüez Campus. Beach sediments were analyzed using three methods, the grain size test (sieves from -4Φ to 4Φ) to determine sorting of sediments at the backshore, the carbonate content (dissolved into HCl), to identify better the percentages of grains in the sample, as well as the mineral composition using a Siemens X-ray Diffractometer (details of the laboratory work are at the appendixes).

**RESULTS**

**Sedimentation**

Grain size distribution at the studied stations varies between them (Figure 3). The most abundant grain size at all stations was 2 phi. Punta Ensenada has a major frequency of 2 phi size (84.55%) than Punta Algarrobo (51.54%), Punta Guanajibo (58.1%) and Punta Arenas (45.0%). Punta Algarrobo and Punta Guanajibo present similar frequencies (% of grain size) at all sizes than the other two stations. The maximum value of coarse sand was 0.4% (Punta Arenas), and the minimum value
(0.01\%) was about lower of 4 phi (Punta Arenas). Punta Arenas has a distribution very irregular between the 0 phi to 3 phi size (4.7\%, 37.9\%, 45.0\%, 10.0\%) compare to Punta Algarrobo and Punta Guanajibo that also has irregular frequency but lower than Punta Arenas.

**Frequency vs. Particle Size**

*Figure 3: Grain Size distributions in sampling sites of the western Puerto Rico.*

Color also varies through stations. Those who are near river systems (Punta Algarrobo, Punta Guanajibo), black sediments dramatically increase, and those who are not, white to pale gray sediments are very abundant. Roundness of grains through all stations were rounded excepts for Punta Arenas (sub-rounded).

The X-ray Diffractometer indicated that the mineral composition between them is very different (Figure 4). Terrigenous sediments, which are characterized by dark color, predominate in facies near river systems (Punta Guanajibo, Punta Algarrobo).
Figure 4: XRD data indicating mineral composition of sand through the stations. A- Punta Ensenada, B- Punta Algarrobo, C- Punta Guanajibo, D- Punta Arenas.

The Punta Ensenada-Punta Algarrobo beach systems are separate to each other, but their composition is very similar. Approximately equal parts of carbonate shell material, quartz and feldspar, and igneous rock material, opaques, and dark minerals increase dramatically in Punta Algarrobo (Figure 5). Most abundant minerals in Punta Ensenada are quartz (40%), following calcite (34%), feldspars (13%), and then lithic fragments or dark minerals (13%). Punta Ensenada beach is separated from the
Aguadilla beach system by the rocky headland at Punta Jiguero (north of Punta Ensenada). Although wave refraction carries some sand from Aguadilla beaches into the Punta Ensenada and Punta Algarrobo beaches.

![Pie charts showing the percentage of different types of grains at different stations.]

**Figure 5:** Relationship between quartz, feldspar, carbonate, and lithic fragments through the study stations.

Punta Algarrobo and Punta Guanajibo have the most similar sediments (Figure 5). The minerals founded in these stations are feldspars (albite), quartz, carbonate (Punta Algarrobo), and lizardite (Punta Guanajibo). Due to the interact of the discharge of the river systems of Río Guanajibo, Río Yagüez, and Río Grande de Añasco, this stations have low percentages of carbonate material very. Punta Guanajibo station shows the highest value of the lithics fragments (90%), having a derivative of the serpentines group,
lizardite (Figure 5). As it was mentioned, in this site no carbonate material was found in Punta Guanajibo.

Punta Arena station has the highest values of carbonate material (80%), values of lithics fragments (4%) and quartz (6%) also characterized this station. The XRD analyses shoe that aragonite, calcite, and dolomite are the carbonate constituents of this station, and evidence of clay minerals (kaolinite) indicate presence of metamorphic minerals such as feldpars (Figure 4). Carbonate material from Punta Arenas are from shell fragments and by the Halimeda flakes. The origins of carbonate material of the other stations are also shell fragments.

Reflectance

The interaction of the electromagnetic radiation with the top layer of sand grains varies between stations. The maximum difference was registered in the infrared region of the spectrum (Figure 6). Punta Ensenada and Punta Algarrobo have similar reflectance, but in the ultraviolet and blue region of the spectrum (350 – 500 nm) the difference on the infrared region increased. Punta Arenas, who was one of the stations used as control, the reflectance intensity was the higher one of all the stations. Punta Guanajibo, the station closest to the Río Guanajibo, shows the lowest reflectance.
**DISCUSSION**

The west coast of Puerto Rico is dominated by the effect of the termination of structural mountain ridges at the shore which are separated by broad alluvial valleys. The ridges form a rocky coast, and the shoreline bordering the alluvial valleys is occupied by sand beaches. The alluvial deposits in the Añasco River valley are similar to the northwest coast, as are the source rocks except for an absence of limestones in the drainage basin. Quaternary alluvial and swamp deposits occur in the Guanajibo river valley. The outcrop source includes serpentinites, limestones, andesites, and volcanoclastics. The general patterns of sand sources for the west coast are rivers, beach erosion, longshore transport between beaches, biogenic process of reef and shells, dunes,
and others. Calcium carbonate is supplied to the beach by the shoreward transport of the shells of marine organisms. The composition changes in calcium carbonate and terrigenous material are a function of the available supply and the transport system. The terrigenous content in the beach sands is greater along the coastline where major rivers are located. A shift toward terrigenous beaches also occurs where an offshore carbonate source is lacking, or shoreward transport is absent. The beaches of the west coast are discontinuous and form separate beach systems with little or no communication. From Aguadilla to Punta Guanajibo, the terrigenous input is dominated by the direct sediment load from the rivers and erosion of the alluvial valley shorelines. Each of the rivers contributes a dominant set of minerals even though considerable overlap occurs. Punta Algarrobo beach is separate to Punta Ensenada by few kilometers, but the wave refraction carries some sand from Aguadilla beaches into the Ensenada – Algarrobo beaches. Composition is very similar between them, but the carbonate material came from biogenic process of coral reef in the Rincón area (Punta Ensenada-Corcega).

Punta Guanajibo to Punta Arenas are part of the Joyuda beach system. Most of the longshore transport from Mayagüez beach area is either piled up at the mouth of the Guanajibo River where it leaves the beach system by offshore process at Punta Guanajibo. Punta Arenas is between Punta Guanajibo and Punta Ostiones and 80 % of its carbonate comes from biogenic interactions by fragments of shell marine organism and Halimeda flakes.

The composition changes in calcium carbonate and terrigenous material are a function of available supply and transport system. The coastal areas containing major rivers have an increase in terrigenous content in the beach sands. There is also a shift toward terrigenous beaches where an offshore carbonate source is lacking. By analyzing
the availability of supply we can draw conclusions about the reflectance and mineral content.

Because of the mayor frequency on size in all stations was about of 2 phi. The reflectance measured is a good indicator to identify their mayor mineral component. Larger concentrations of calcium carbonate can indicate larger reflectance (Punta Arenas) than those who have larger concentration of lithics fragments (Punta Guanajibo) where the reflectance is lower. Spectral ratios between the visible (in this case the blue) and infrared regions of spectrum could be used to say something about the composition of the sands (Table 1).

<table>
<thead>
<tr>
<th>Station</th>
<th>Rrs 1 (850 nm)</th>
<th>Rrs 2 (400nm)</th>
<th>Ratio</th>
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<tr>
<td>Punta Ensenada</td>
<td>0.1068</td>
<td>0.0342</td>
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<td>Punta Algarrobo</td>
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<td>2.556</td>
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<td>Punta Arenas</td>
<td>0.1311</td>
<td>0.0689</td>
<td>1.903</td>
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Table 1: Remote sensing spectral ratios of the west coast beaches of Puerto Rico.

Spectral ratios indicate that Punta Ensenada reflects more the infrared band than the other stations. This can be possible because higher concentration in quartz showed bigger ratio values. As a preliminary study the spectral ratio can be used to identify mineral composition of sand.

**CONCLUSIONS**

Spectral measurements such as remote sensing reflectance (Rrs) are a practicable tool to obtain information of an object. In this case determining the reflectance and
spectral ratio in beaches of the west part of Puerto Rico, made possible to correlate sedimentation and spectral characteristics. Because the sources of sand are different for the studied stations, the spectral ratio showed to be a practical method to detection of differences in chemical composition (Table 1).

This preliminary research establishes the basis for the application of remote sensing in further studies of Puerto Rican beaches. The evidence suggests that remote sensing technique, as reflectance measurements, could be used to identify differences in mineral composition on beaches of Puerto Rico.

REFERENCES


APPENDIX 1

GPS positions at study stations.

<table>
<thead>
<tr>
<th>Punta Ensenada</th>
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<td>67º 11.262'</td>
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APPENDIXE 2

Digital Photos of the study stations

Punta Ensenada

Punta Algarrobo
Punta Guanajibo

Punta Arenas
APPENDIX 3

Steps used to identify the grain size of sand

1. A small amount of the sample (± 50 g – 100 g) was taken and placed in the oven. It was dried for one day.

2. The sample was taken out of the oven, and leaved for about 10 minutes. The sample cooled by itself and the weight of the dry sample was measured.

3. The sieves were arranged in the follow order: 16mm, 8mm, 4mm, 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, 0.063mm, Pan.

4. Small bags were used to fill the weight fractions.

5. The weight of the small bag was measured, dipping the “zero” key in the balance machine to put it in zero. Subsequently, the weight fraction with the bag was measured. That was the true weight of the fraction.

Steps for dissolve carbonates

1. Around ± 5 grams of the sample was taken.

2. The sample was deposited inside a 25 or 40 ml beaker and filled it with ± 15 ml of HCl 10%.

3. The acid was leaved to dissolve the Calcium Carbonate (CaCO₃) for a couple of days.

4. The excess of acid HCl that did not react with the sample was removed by decantation and throwed away.

5. The sample was rinsed with water and the decantation process was repeated.
6. The sample was placed to dry for one day, and then it was cooled and weighed.

7. The changes in percentage of carbonate were determined.

**Steps followed for identify the mineralogy of sand**

A Siemens D5000 X-ray Diffractometer was used to determine mineral composition for the sediment study sites (Figure 7).

![Siemens D5000 goniometer diffractometer in the X-ray unit.](image)

**Figure 7: Siemens D5000 goniometer diffractometer in the X-ray unit.**

1. The samples of the different sites were pulverized completely, then poured on a XRD sample holder.
2. The poured sample was deposited into the XRD machine.
3. The mineral content was identified using a computer identification program.
4. The source and possible sedimentation effects were determined after analyzing the mineral content.