

THE PROGRESSION OF SEDIMENTOLOGICAL FACIES AND THEIR CONTROL OF BIOGEOCHEMICAL CYCLING IN THE BIOLUMINESCENT BAYS OF VIEQUES, PUERTO RICO

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INTRODUCTION

This study explores the interactions of the physical environment, biological communities, and sedimentary facies in order to understand the history of physical and environmental conditions in the bioluminescent shallow tropical lagoons of Vieques, Puerto Rico. It extends work of D'aluisio-Geurieri (1982), who described historical sedimentation in the bays and compares these results to a map of the distribution of ecological communities in the bays that was produced by NOAA (1999).

METHODS

Skin diving transects were used to describe communities from ecological maps (NOAA 1999). At least two transects were taken across Puerto Mosquito, Puerto Ferro, and Bahia Tapon to obtain qualitative data on bioturbation, macrofaunal assemblages, surface sediment, and turbidity, the latter using a secchi disk.

Cores taken from various environments in the bays were described, and samples were taken for further analysis. Grain size, sorting, and clast types were determined through visual assessment. Color was determined through comparison of wet sediment samples with Munsell Soil Color Charts. Energy dispersive X-ray fluorescence spectrometry was done to determine major and minor elemental concentrations according to the auto-quant powders routine powder in a Panalytical Epsilon 5 machine.

RESULTS

Modern Environmental Conditions

Three distinct water-surface environments are in each bay: near shore, bay center, and the channel between the bay and ocean. The marginal areas of the bays have higher turbidity according to secchi disc readings: .03 +/- 0.17 m (n=4) in Puerto Mosquito, 1.6 +/- 0.1 m (n=2) in Puerto Ferro, and 0.5 +/- 0.14 m (n=2) in Bahia Tapon. The centers of the bays have lower turbidity: 1.8 m in Puerto Mosquito, 3.0 m in Puerto Ferro, and 1.1 m in Bahia Tapon. The channel areas were not measured, but they have the greatest water clarity.

	Dense Seagrass	Patchy Seagrass	Scattered Seagrass	Macroalgae	Halophila	No Vegetation
Sediment Cover	> 95%	50-95%	< 10%	10-100%	~ 60%	0%
Sediment Type	Mud & Sand	Mud & Sand	Mud	Mud & Sand	Sand	Mud
Macroflora Present						
<i>Thalassia testudinum</i>	●	●	○	○		
<i>Halodule beaudettei</i>	●	●		○		
<i>Syringodium filiforme</i>	●					
<i>Halophila dicipiens</i>					●	
<i>Halimeda icrassata</i>	○	●		●		
<i>Avrainvillea spp.</i>		●	○	●		
<i>Penicillus capitatus</i>	○	●		●		
<i>Udotea flabellum</i>			○			
<i>Halimeda monile</i>				●		
<i>Acanthophora spicifera</i>	○			●		

Table 1. Community Descriptions
Sediment cover is the amount of the sediment surface covered by macroflora. Closed circles represent dominant species. Open circles represent species that are present but not dominant.

Modern Ecosystem Description

The bays are mangrove-fringed shallow tropical lagoons. Calcareous algae and seagrasses are the dominant macroflora in the lagoons. Macrofauna include various mollusks and *Callianassid* shrimp. Six different biological communities exist within the study area, and these are described in Table 1. Dense seagrass is the dominant competitor in areas of adequate light penetration to the sediment surface and stable substrates. Patchy seagrass is a transitional community that exists where seagrasses are limited because of some combination of high wave action, light limitation, and substrate disturbance through bioturbation. Scattered seagrass occurs at shallow to intermediate depth in very high turbidity water. The macroalgae community covers bioturbated areas where there is intermediate to low turbidity and shallow to intermediate water depths. In this community rapid bioturbation or nutrient limitation limits the growth of seagrasses; however, light limitation does not have an effect because many of the macroalgae that exist in the community are more sensitive to low light levels than seagrasses. The *Halophila* community occurs where low light conditions accompany a sandy, bioturbated substrate. The no vegetation zone exists in the deepest parts of all three bays where light is very limited. Overall, the key factors controlling the distribution of these different communities are water depth and turbidity, which together control light penetration to the sediment surface; substrate type; and substrate stability.

Surface Facies

Terrigenous Alluvium was described and mapped in the study area by D'aluisio-Geurieri (1982). It is sandy mud composed of terrigenous sediment. Terrestrial root material indicates that this facies was deposited subaerially.

Shell Hash Gravelly Sand and Sandy Gravel is poorly sorted with 35 to 95% coarse sand to

pebble sized, broken, angular shells in a silt to fine sand carbonate-dominated matrix. Poor sorting and large clast sizes indicate that the depositional environment of this facies was highly energetic. It could either represent a transgression lag or a storm deposit.

Neritina Mud is a poorly sorted sandy mud with rare shells including *Neritina virginea* and *Neritina punctulata*, which are indicative of an intertidal mud-flat environment (D'aluisio-Guerri 1982).

Molluscan Gravel is composed of well preserved, whole, often articulated mollusk shells in a muddy to sandy matrix. These mollusks "inhabit the sediment 10 to 20 cm below the surface" in areas beneath seagrass beds (D'aluisio-Guerri 1982). This facies is interpreted as representing deposition in turbid water in intermediate water depths.

Seagrass Peat is composed of beds of the roots and blades of *Thalassia Testudinum* and *Halophila dicipens*, and in cases has decomposing mangrove leaf litter. It is indicative of high seagrass productivity and low energy.

Halimeda Sand is composed of whole plates of *Halimeda incrassata*, mixed with varying amounts of matrix material. *Halimeda* sand is indicative of low-turbidity water conditions. It is accumulating where there is limited sedimentation and abundant *Halimeda incrassata*.

Carbonate Mud is dominated by well-sorted mud. It is indicative of relatively deep-water environments with intermediate turbidity. In the modern, it is accumulating in the center of the bays.

Bioturbated Gravelly and Sandy Green Mud is composed of terrigenous mud with burrows filled with shell hash gravel. The mud contains organic material that appears to be the remains

of mangrove roots. This facies indicates near-shore submarine deposition and high turbidity.

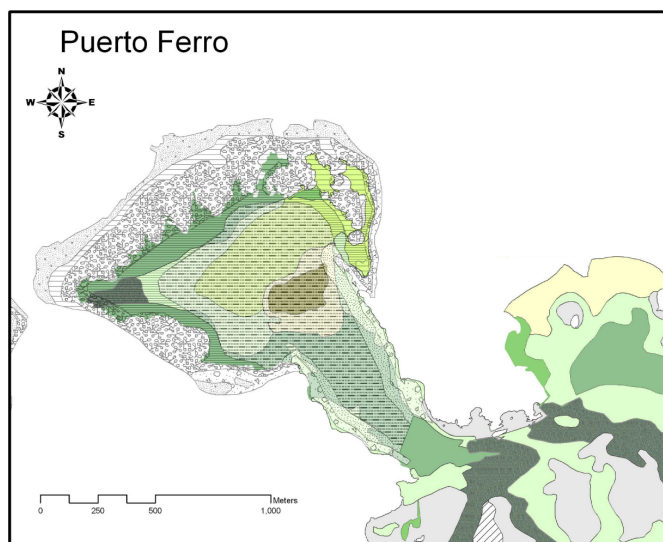
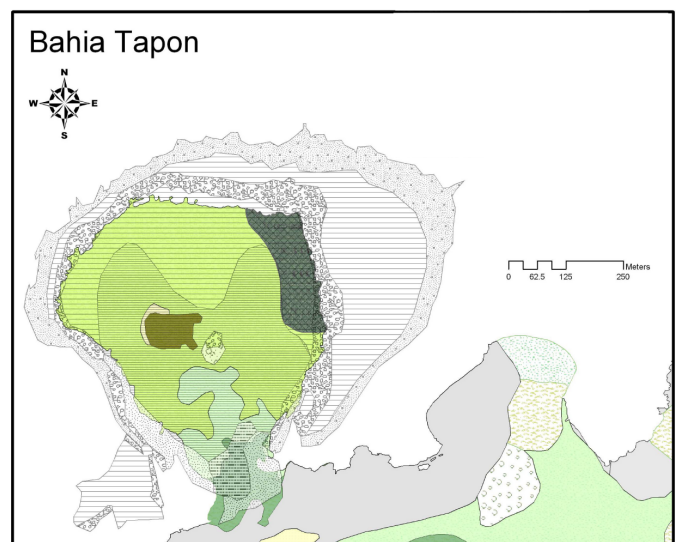
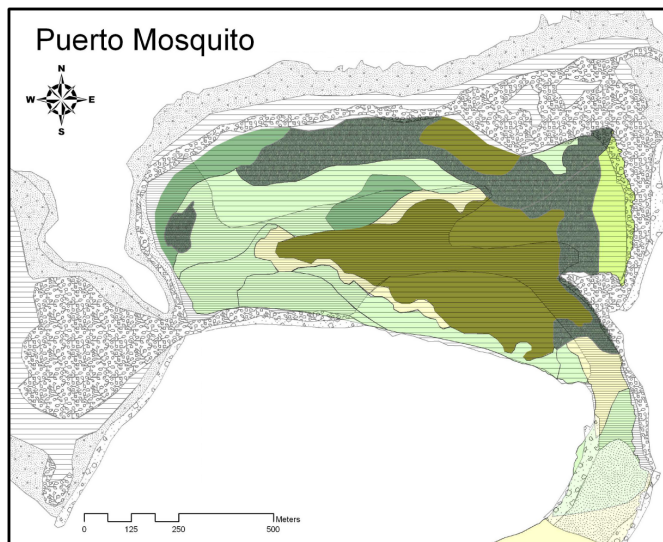
Terrigenous Mud is restricted to the top beds of the landward margins of the lagoons. It is well sorted. This facies is indicative of extremely high water turbidity and limited growth of macroflora. It is restricted to the modern landward sides of the bays.

Mangrove Peat is composed of organic material from populations of *Rhizophora mangle*. It is indicative of a stable shoreline position and is accumulating at elevations that are within, and slightly above, the microtidal range.

Mixed Skeletal Sand is poorly sorted sand. Large clast sizes and an absence of fine-grained matrix indicate very high-energy, wave-dominated environments.

Correlation of Ecological Communities and Sediment

A multivariate chi-squared test determined that overlap of the facies and communities is distinct from that expected from a random overlap of the classes ($p < 0.001$), which confirms the assumption that ecological communities and lithotope classes are linked.



Legend

Lithotopes

- Mangrove
- Carbonate Mud
- Terrigenous Mud
- Skeletal Sand
- Terrigenous Alluvium
- Limestone Boulder
- Halemeda Sand

Biological Communities

- Mud with no Vegetation
- Dense, Continuous Seagrass
- Patchy, Discontinuous Seagrass
- Scattered Seagrass
- Macroalgae Dominated
- Hardbottom

Figure 1. Maps comparing the distributions of lithotopes with the distribution of biological communities. The maps of lithotopes are modified from D'Aluisio-Guerrero (1982) and the maps of biological communities are modified from NOAA (1999)

In Puerto Mosquito, the most common groupings are of terrigenous and carbonate mud with scattered seagrass and no vegetation. In Puerto Ferro, the common pairings are both *Halimeda* sand and carbonate mud with dense seagrass, and *Halimeda* sand with scattered seagrass, dense seagrasses, and macroalgae.

In Bahia Tapon, the common pairings are of both carbonate and terrigenous mud with macroalgae. Figure 1 shows a map of these distributions. The most common and statistically unique pairings are described below.

The terrigenous mud and scattered seagrass association is the result of high-turbidity conditions, which cause severe light limitation. The terrigenous mud and no vegetation, and the carbonate mud and no vegetation, pairings exist in areas where depth or turbidity limit light to the degree that no macroflora grow. The carbonate mud and discontinuous seagrass, and carbonate mud and dense seagrass, associations occur in areas where turbidity is low enough for seagrass growth but biogenic sedimentation is also occurring.

The terrigenous mud and discontinuous seagrass pairing occurs in an area where terrigenous sedimentation does not create highly turbid conditions that completely choke macrofloral growth. The skeletal sand and patchy seagrass pairing exists where water movement removes fine sediment, and low turbidity allows the growth of dense macroflora populations. The pairings of *Halimeda* sand with macroalgae, dense seagrass, and patchy seagrass exist because *Halimeda* sand is directly produced by the breakdown of the macroalgae *Halimeda incrassata*, a dominant species in these zones. There is little other sedimentation over much of these seagrass communities. The associations of limestone boulder and discontinuous seagrass, and skeletal sand and patchy seagrass, exist because extremely high-energy storm events deposit these facies where the channel is exposed to ocean waves which, along with

low turbidity, encourage patchy seagrass. The *Halimeda* sand and mud with no vegetation pair exists only in the deep part of Puerto Ferro, where *Halimeda* is transported into this zone from surrounding areas. The carbonate mud and macroalgae, and terrigenous mud and macroalgae, pairings exist in areas where macroalgae are the dominant sediment-surface cover and where biogenic or terrigenous sedimentation overwhelms sedimentation from *Halimeda*. The skeletal sand and dense seagrass, and *Halimeda* sand and dense seagrass, pairings exist where stable, sandy sediment encourages seagrasses growth.

DISCUSSION AND CONCLUSIONS

Modern Interactions of Biological Communities, Sediment, and Environmental Conditions
Figure 2 provides a summary of the interactions between the different components of this system. The most important factors controlling both facies and biological communities are turbidity and water depth. Turbidity is correlated to the amount of fine sedimentation, and in conjunction with depth, controls the biological communities, which in turn influence sedimentation. The sediment, therefore, primarily provide a record of depth and average turbidity.

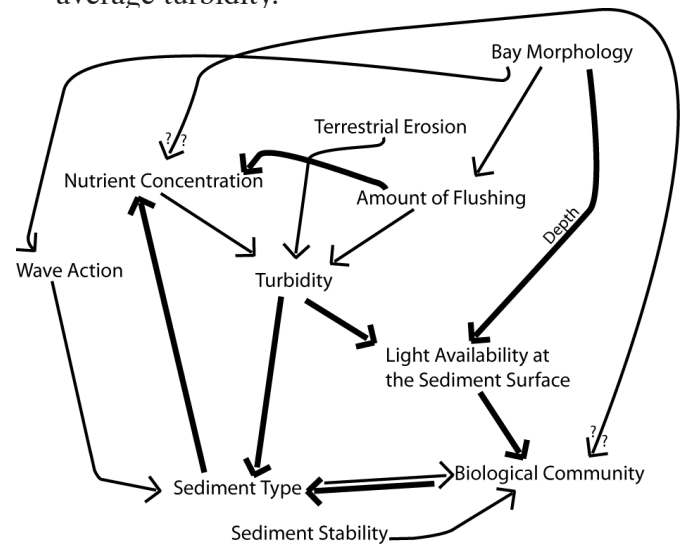
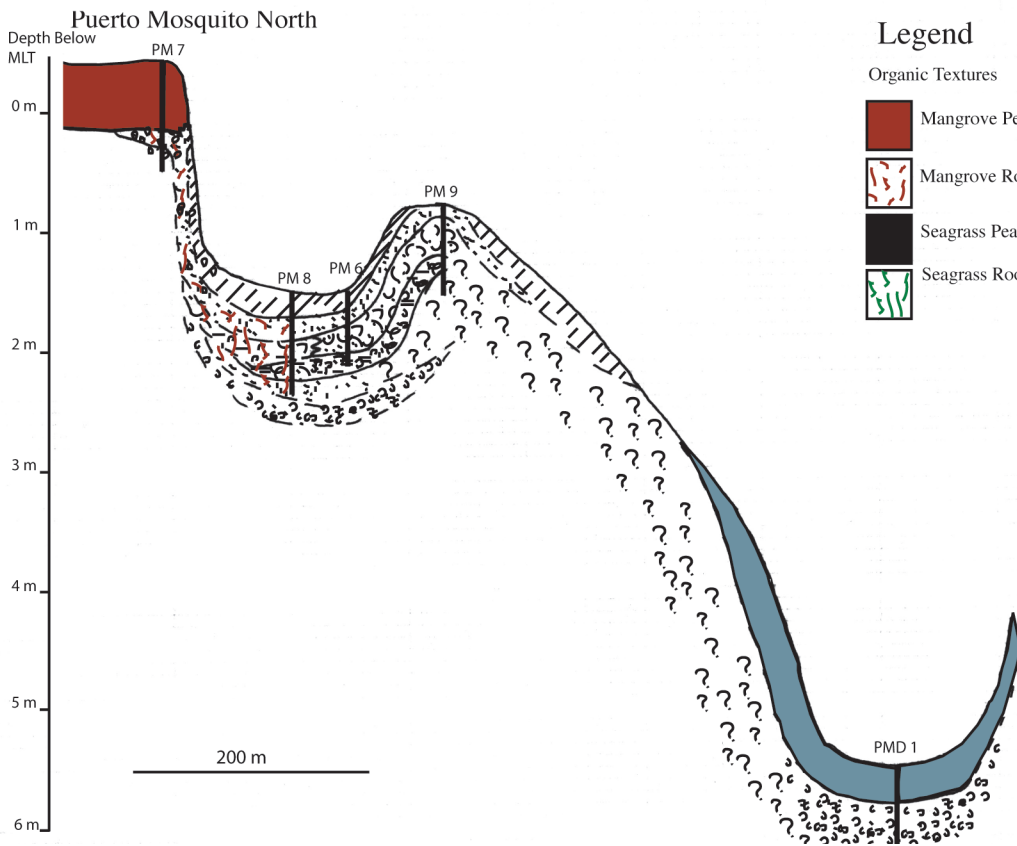
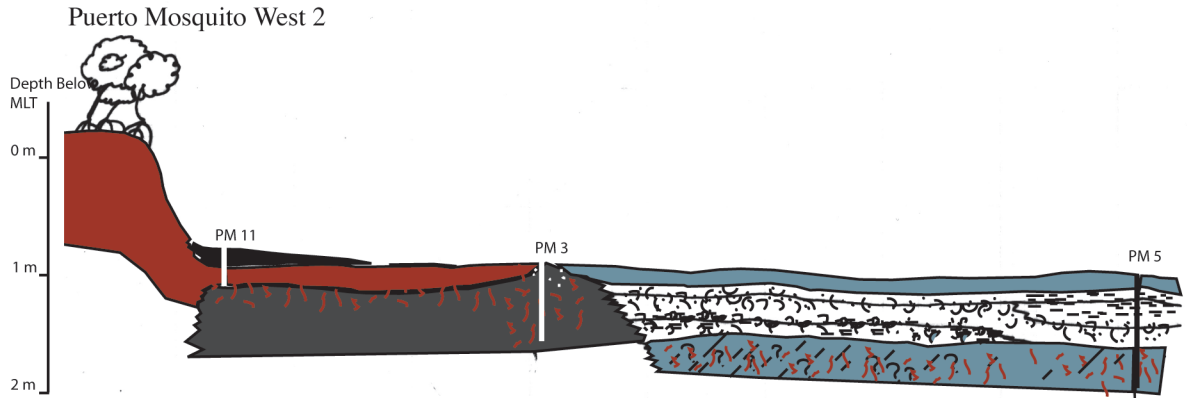
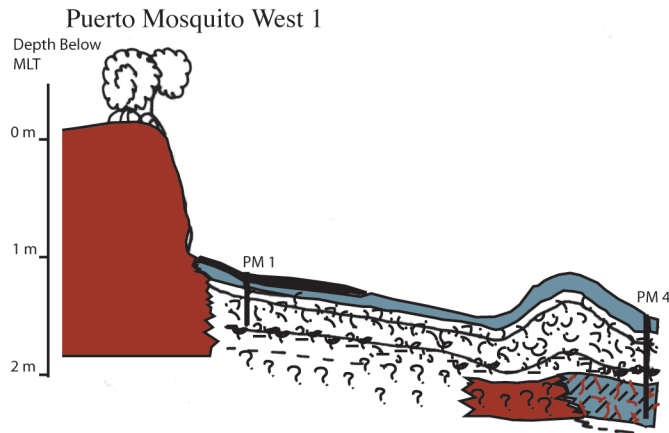


Figure 2. Key paths of influence between the sediments, biological community, and environment. Bold arrows indicate dominant paths.

Figure 3. Puerto Mosquito Cross Sections



Legend		Sediment Textures	
Organic Textures			Carbonate Mud
	Mangrove Peat		Terrigenous Mud
	Mangrove Roots		Silt
	Seagrass Peat		Halimeda Sand
	Seagrass Roots		Mixed Skeletal Sand
			Gravel
			Limestone Boulder
			Molluscan Gravel
			<i>Neritina</i> Gravel
			<i>Crassostrea rhizophora</i>
			Terrigenous Alluvium

Sedimentological History

D'aluisio-Geurieri (1982) describes an ideal succession of facies for these bays, as seen in Puerto Mosquito, and interprets it as a record of Holocene sea-level rise. This project presents greater detail of the facies and improved understanding of the relationship of sedimentation and sea-level change. The western part of Puerto Mosquito (Fig. 3) records a more complex history of sea level change in the bays. Bioturbated gravelly and sandy green mud, which reflects submarine terrigenous sedimentation, lies beneath shell hash gravelly sand and sandy gravel, which represents either a transgressive lag or a storm deposit in deeper water. Its stratigraphic location, above a deposit that was shallow and near to the shore, and below a deeper-water deposit (molluscan gravel), indicates that it is a transgressive lag. A regressive-transgressive succession is therefore recorded by the superimposition of these two facies. The overlying facies is molluscan gravel, which is indicative of intermediate water depths and a vibrant macrofaunal community.

There is also a record of *Halimeda* sand accumulating contemporaneously with the molluscan gravel, which indicates that some parts of the bay during this period of time had lower turbidity.

In the northern part Puerto Mosquito (Fig. 3) there is another record of a regressive-transgressive succession. The stratigraphically lowest unit is the intertidal to slightly subtidal *Neritina* mud. This is overlain by an ambiguous deposit of fine carbonate sand, which is in turn overlain by shell hash gravelly sand and sandy gravel. Although this facies could be interpreted as a storm deposit, the similar elevation of this deposit relative to sea level in both the eastern and western part of the bay, indicates that it was probably deposited by the same transgressive pulse. This transgressive deposit is then overlain by deeper water facies. Terrigenous mud is being deposited in the modern environment, which indicates that a recent turbidity increase has shut off marine productivity and caused deposition of terrigenous material.

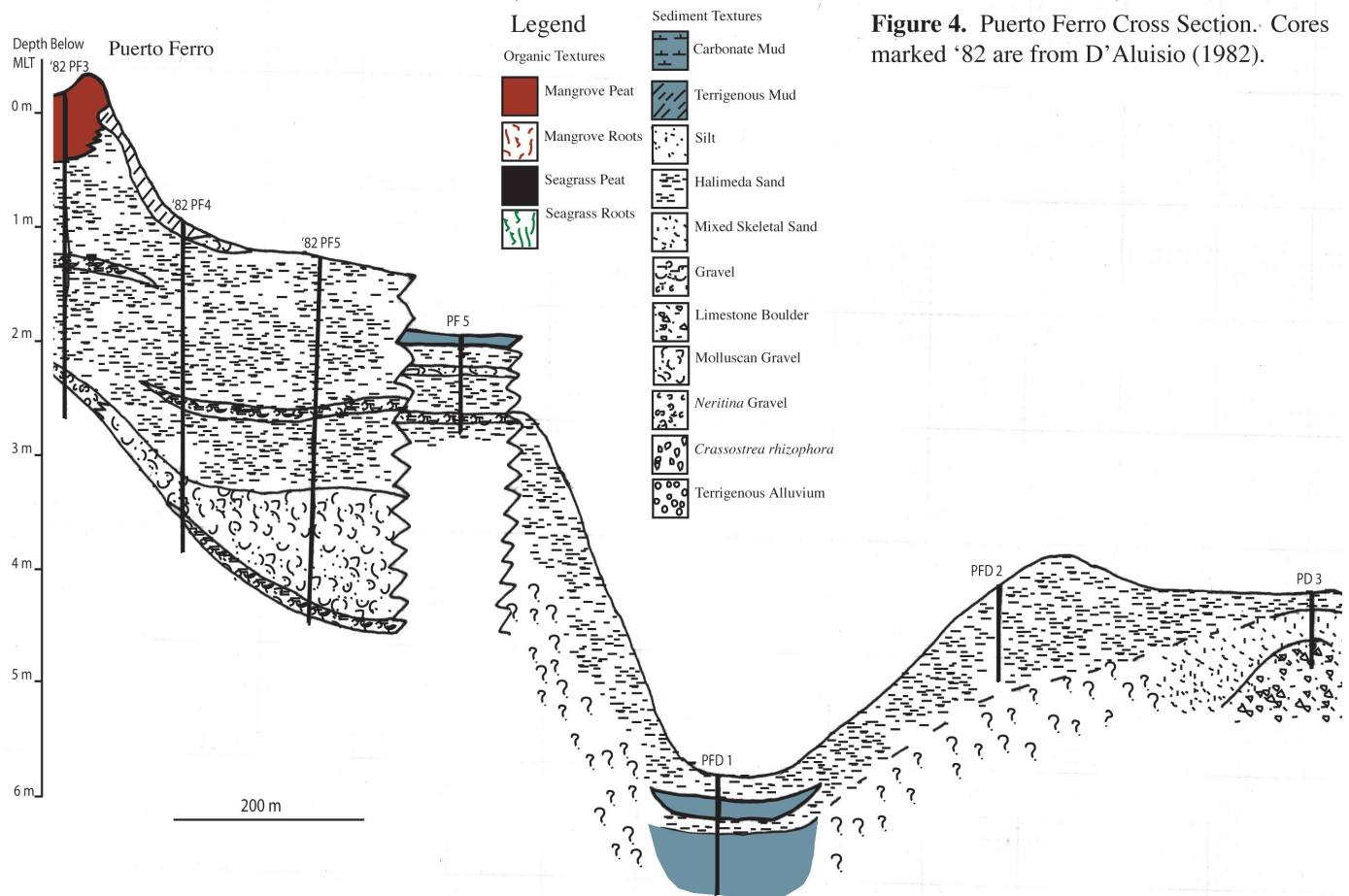


Figure 4. Puerto Ferro Cross Section. Cores marked '82 are from D'Aluisio (1982).

A core from the deep part of Puerto Mosquito has Neritina mud directly overlain by carbonate mud. This shows that intertidal water depths dominated even the deepest part of the basin, and that a rapid transition to very deep water occurred, at some point in the past.

The overall sedimentological history of Puerto Ferro (Fig. 4) shows a record of transgression, but the fine detail of second-order regression and transgression within the overall transgression are not apparent. In the northern part of Puerto Ferro, a typical transgressive succession is preserved: terrigenous alluvium, overlain by shell hash gravely sand and sandy gravel, overlain in turn by molluscan gravel, and finally a thick upper layer of *Halimeda* sand (D'aluisio-Guerri 1982). A recent increase in turbidity is indicated by terrigenous mud that is accumulating in the most shoreward areas of the bay.

Core PF5 shows a similar parallel development. *Halimeda* sand, which represents *Halimeda* productivity and low water turbidity, is punctuated by beds of shell hash gravely sand and sandy gravel, which represents either storm events or regressive-transgressive successions. Vast accumulations of *Halimeda* indicate that Puerto Ferro had low turbidity, which is probably related to its openness to the ocean.

Of the three bays, the sedimentological record of Bahia Tapon is the most complex. D'aluisio-Guerri (1982) describes in detail how this record is indicative of the ways in which the environment of Bahia Tapon frequently changed. This pattern is confirmed by limited sampling from this study. Overall, in Bahia Tapon, although the record is ambiguous, a transgression is recorded.

REFERENCES

- D'Aluisio-Guerrieri, Gary M., 1982, Holocene Lagoonal Sedimentation Vieques, Puerto Rico [unpublished masters thesis]: Tampa, University of South Florida, 126 p.
- NOAA, 1999, Benthic Habitats of Puerto Rico and the U.S. Virgin Islands: Project Methods, Online. <<http://ccma.nos.noaa.gov/products/biogeography/benthic/htm/develop.htm>>