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21ST KECK RESEARCH SYMPOSIUM IN GEOLOGY SHORT CONTRIBUTIONS

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Keck Geology Consortium
Franklin & Marshall College
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John Garver (Union College), Mark Brandon (Yale University), Alison Anders (University of Illinois), Jeff Rahl (Washington and Lee University), Devin McPhillips (Yale University)
Students: William Barnhart, Kat Compton, Rosalba Queirolo, Lindsay Rathnow, Scott Reynhout, Libby Ritz, Jessica Stanley, Michael Werner, Elizabeth Wong

Geologic Controls on Viticulture in the Walla Walla Valley, Washington
Kevin Pogue (Whitman College) and Chris Oze (Bryn Mawr College)
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Brennan Jordan (University of South Dakota), Bob Wiebe (Franklin & Marshall College), Paul Olin (Washington State U.)
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Kurt Hollocher (Union College)
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Students: Erin Algeo, Jennifer Bourdeau, Justin Clark, Margaret Selzer, Ulyanna Sorokopoud, Sarah Tracy

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THE BIOGEOCHEMISTRY AND ENVIRONMENTAL HISTORY OF BIOLUMINESCENT BAYS, VIEQUES, PUERTO RICO

TIMOTHY C.W. KU: Wesleyan University
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ANNA M. MARTINI: Amherst College

INTRODUCTION

Bioluminescent bays are spectacular wonders of nature and some of the brightest bays are found along the southern coast of Vieques (Fig. 1). Here, the bioluminescent glow is primarily caused by high abundances of the dinoflagellate *Pyrodinium bahamense* var. *bahamense*, which releases brilliant bursts of blue light when agitated (Fig. 2). The most famous bioluminescent bay in Vieques is Puerto Mosquito where standing *Pyrodinium bahamense* populations range between 10,000 and 161,000 individuals per liter (Seliger et al. 1969; Walker, 1997). Persistent populations of bioluminescent dinoflagellates exist in a dynamic balance between effective water flushing rates and biological generation, with the latter likely limited by nutrient availability (Carpenter and Seliger, 1968; Seliger et al., 1971). While these factors are qualitatively understood, most of the previous work has focused on plankton compositions with relatively few studies quantifying the hydrodynamic and nutrient factors that influence these populations (Burkholder and Burkholder, 1958; Seliger et al., 1970; 1971;Walker, 1997; Gilbes and Armstrong, 2006).

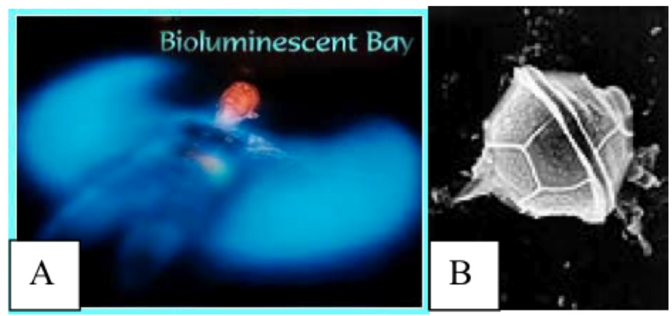

Figure 2: A) Visitor to the Puerto Mosquito creates a light show by moving arms. B) The dinoflagellate Pyrodinium bahamense var. bahamense. The typical diameter of an individual is 0.05 mm. (images from: http://www.biobay.com/)

Historically, much of the research of *Pyrodinium* has focused on the variety *compressum*. Variety compressum produces saxitoxin, a neurotoxin that causes paralytic shellfish poisoning (PSP) and harmful algal blooms (HAB) (Maclean, 1989; Azanza and Taylor, 2001). *P. bahamense* var. *compressum* is common in the Pacific Ocean while *P. bahamense* var. *bahamense* generally occurs in the Atlantic Ocean and has historically been considered nontoxic (Steindinger et al., 1980; Azanza and Taylor, 2001). However, recent studies from the Indian River Lagoon in Florida discovered that Atlantic *Pyrodinium*

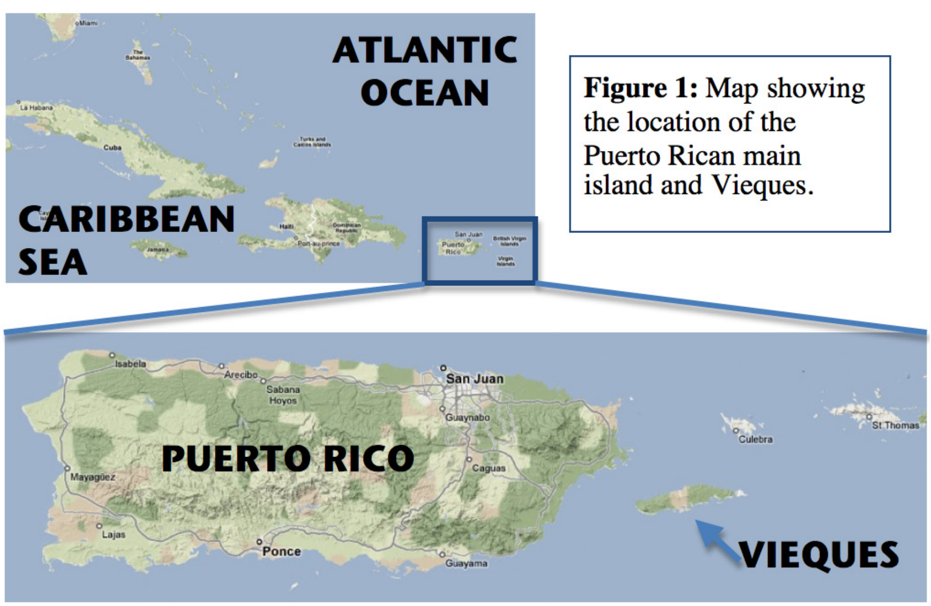

Figure 1: Map showing the location of the Puerto Rican main island and Vieques.

bahamense can carry saxitoxin and are likely responsible for saxitoxin accumulation in puffer fish (Landsberg, et al. 2002; 2006). The consumption of puffer fish from this lagoon has led to at least 28 cases of puffer fish poisoning (PFP) and harvesting puffer fish is currently banned in those waters (Landsberg et al., 2006).

Globally, occurrences of dinoflagellate related HAB blooms and poisonings, such as in the Indian River Lagoon, have been increasing due to coastal eutrophication and global climate change (Dale et al., 2006; Gilbert and Burkholder, 2006). The primary goal of the project is to determine the present and past environmental conditions that sustain blooms of *Pyrodinium bahamense* var. *bahamense* by comparing three adjacent bays on the south side of Vieques. From west to east, the three bays are Puerto Mosquito, Puerto Ferro, and Bahia Tapon (Table 1; Fig. 3). Puerto Ferro and Bahia Tapon lie within the present-day Vieques National Wildlife Refeuge (VNWR) and presently have low-intermediate concentrations of dinoflagellates, but past studies indicated that Bahia Tapon had higher concentrations than Puerto Mosquito (Table 1; Fig. 3; Cintron and Maddox, 1972).

	Puerto Mosquito	Puerto Ferro	Bahia Tapon
*Area (m^2)	749,000	886,000	252,000
*Max. depth (m)	3.4	9.4	1.7
*Avg. depth (m)	2.0	3.4	0.84
Mouth width (m)	81	237	95
**Pyrodinium* (cells/mL)	1 –20 (10-161)#	0-0.4	0-18 (80)#
**Pyrodinium cells*	Abundant	Rare	Low-variable

*Table 1: Bay comparison. *initial data collected during the 2006 Keck program. #past data from Seliger et al. (1969), Cintron and Maddox (1972), and Walker (1997).*

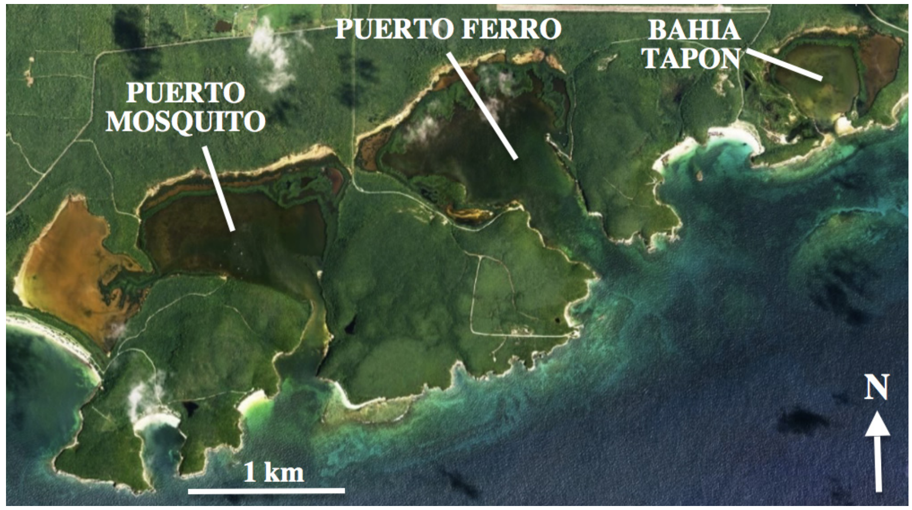

Figure 3: Three bays of interest along the southern coast of Vieques. From west to east the bays are Puerto Mosquito, Puerto Ferro, and Bahia Tapon.

GEOLOGIC SETTING AND VIEQUES HISTORY

Vieques is a 54 square mile island that is 21 miles long and 5 miles wide off the east coast of Puerto Rico (Fig. 1). It is composed of Upper Cretaceous volcanic rocks and Upper Cretaceous/Lower Tertiary intrusive rocks. These rocks formed when Puerto Rico and Vieques were part of an active subduction zone. About 45 million years ago subduction shifted to the Cayman Trench and the active volcanism to the east (e.g. Montserrat), (Schellekens, 1999). The igneous rocks are overlain by layered Neogene limestone, some of which is uplifted, forming steep outcrops, particularly along the southern and eastern coasts.

Seagrass beds, shifting sand bars and shallow coral reefs form immediately offshore. Dense mangrove swamps line large portions of the coast, especially the southern coast. A ridge runs through the island center creating distinct ecological zones with the highest point, Mt. Pirata, reaching 301 m. The steep slopes and irregular rain can easily erode the soils and move them to the coastal areas causing siltation problems (D'Aluisio et al., 1988, Seliger, 2001).

The bioluminescence waters are a popular tourist attraction and several boat and kayak companies offer daily tours of Puerto Mosquito. In the Puerto Mosquito watershed, land development has increased in recent years, especially since 2003 when much of the island was transferred from the Department of Defense (DoD) to the U.S. Fish and Wildlife Service (USFWS) creating the Vieques National Wildlife Refuge (VNWR) (Mitchell, 2005). Previously, the DoD owned ~79% of Vieques and the island was used for military operations.

The Puerto Rico Department of Natural Resources (DNR) maintains Puerto Mosquito and conservation practices such as the use of electronic boat motors have helped maintain the ecosystem; however, anthropogenic histories of other bioluminescent bays indicate that Puerto Mosquito may still be at risk. For example, Bahia Fosforescente (La Parguera Bay) located on the Puerto Rican main island has seen a decline in bioluminescence by more than 80% in the last decade (Gilbes and Armstrong, 2006) and average Pyrodinium bahamense populations have declined from 10,000-90,000 cells/L in 1969 (Seliger et al, 1971) to 1,500-29,000 cells/L in 1996 (Walker, 1997). These decreases are associated with heavy human development of the La Parguera watershed. A detailed understanding of the factors controlling the dinoflagellate population in Puerto Mosquito is necessary if that ecosystem is to be preserved.

RESEARCH APPROACH

To constrain the modern and past environmental conditions necessary to sustain Atlantic Pyrodinium bahamense blooms, our field and laboratory efforts aimed to determine 1) the origin and accumulation rates of the organic matter and detrital sediments, 2) the nutrient limitations for primary productivity, 3) the net organic matter decomposition rates and the specific biological and chemical pathways by which N and P are released, 4) the residence time of bay waters relative to exchange with the Caribbean Sea, and 5) the geologic history of each bay as recorded by faunal assemblages (bivalves and ostracods), sedimentary facies, and geochemical indicators preserved in the sedimentary record.

Students and faculty spent two weeks in Vieques

Figure 4: A, B) Students collecting sediment cores using the percussion corer, C) The team describing and sampling a sediment core, and D) The group prepares to extract a vibracore.

collecting and preserving seawater, pore water, microbial populations, modern organic sources (seagrass, mangroves, plankton), and sediment cores (percussion corer and vibra corer) (Fig. 4). In addition, a Rhodamine WT dye tracing experiment was conducted to measure bay water flushing rates and field experiments were deployed to measure the benthic flux of phosphate and trace metals. Participants spent two additional weeks at Wesleyan University or Amherst College. There, initial sediment and water analyses were performed and samples divided among the students for further work at their home institutions.

STUDENT PROJECTS

Erin Algeo (Trinity University) investigated the biogeochemistry of the modern seagrass Thalassia testudinum and the history of organic matter deposition. To determine if primary production is limited by nitrogen, phosphorous, or light, she measured the C/N/P ratios and isotopic compositions ($\delta^{13}C$ and $\delta^{15}N$) of the seagrass at several sites in the bays. In collaboration with Justin Clark (below), Erin also used a three end-member C/N – $\delta^{13}C$ model to determine the relative contribution of plankton, mangroves, and seagrasses to the total sedimentary organic matter. This sedimentary history will document the relative importance of plankton burial over the past ~3,000 years.

Jennifer Bourdeau (Mount Holyoke College) examined the ostracod assemblages and in particular, measured the abundance and shape of the pores on Cyprideis. The occurrence of circular to oval carapace pores in this species is related to water salinity. Jennifer is using this paleosalinity proxy to help us better understand the history of these bays as relative sea levels rose to create the semi-protected bays we see today.

Justin Clark (University of Arizona) measured the stable isotope composition ($\delta^{13}C$ and $\delta^{15}N$) of the modern mangroves surrounding the bays and analyzed the C/N, $\delta^{13}C$ and $\delta^{15}N$ values of the sedimentary organic matter in both Puerto Mosquito and Puerto Ferro. Together with Erin Algeo (above), Justin traced the sources of sedimentary organic matter through time using a C/N - $\delta^{13}C$ model. In addition, he interpreted the $\delta^{15}N$ values of the sedimentary organic matter for information regarding anthropogenic contributions, diagenetic alterations, and nitrogen nutrient limitations.

Margaret Selzer (Franklin and Marshall College) examined the molluscan fauna to reconstruct the paleoenvironmental history of Puerto Mosquito and Puerto Ferro. Based on species compositions, taphonomical indices, and statistical analyses, she documented the progression of ecology, morphology, and sedimentary facies of the bays as relative sea level rose over the last ~4,000 years. Margaret's work establishes the past depositional environments and combined with sediment mineralogies and geochemistries, provides us with a detailed history of the bays.

Ulyana Sorokopoud (Wesleyan University) studied the biogeochemical cycling of metals (iron, manganese, zinc, and copper) and phosphate by using DGT (diffusive gradients in thin-films) techniques in conjunction with sediment chemistries. The DGT methods determine the flux of these elements released within the sediment and the concentrations in the overlying seawater. These results are used to evaluate the relative importance of metal redox processes to the nutrient budgets of the bays.

Sarah Tracy (Amherst College) investigated the chemistries of the overlying seawaters, pore waters, and sediments to quantify the microbial degradation of organic matter and the associated release of nutrients. She also employed the molecular techniques of DNA sequencing, T-RFLP (terminal-restriction fragment length polymorphism), and FISH (fluorescent in-situ hybridization) to characterize the sediment bacterial populations that control the rate and pathways of organic matter decomposition.

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