15th International Conference on Environmental Science and Technology

Rhodes, Greece, 31 August to 2 September 2017

Combined Effect of Ocean Acidification and Fluid Turbulence on Puerto Rico Coastal Barriers: A Preliminary Study

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Abstract. A wealth of information exists on the effects of ocean acidification (OA) on marine ecosystems. Acidifying oceans not only pose a threat to coral colonies and reef formations, but may also alter dissolution processes of other coastal barriers such as sandstone. In this paper, we examine the combined effect of OA and fluid turbulence on the Puerto Rico north coast barrier (Eolianite). We hypothesize that fluid turbulence adds an additional stressor, whose combined effects on the dissolution processes are yet to be determined. Eolianite samples were subjected to fluid stresses while submerged in seawater with lower-than-usual pH levels ($6.5<pH<6.9$). For this preliminary experiment, the integrity of the sample was assessed in terms of its mass loss (25.8g average). Future experiments include assessments of mechanical, physical, and chemical properties, including roughness, point load stress, morphology, and carbonate composition. We ultimately aim at developing dissolution models for eventual extrapolation into field conditions. This highly interdisciplinary project supports the basis for more comprehensive efforts aiming to provide estimates of the accelerated loss of coastal barriers, OA threats, aragonite saturation, coastal vulnerability and hazards to public safety.

Keywords: Ocean Acidification, Coastal Barriers, Eolianites, Fluid Turbulence, Coastal Management

1. Introduction

According to the US National Oceanic and Atmospheric Administration (NOAA) "…the pH of surface ocean waters has fallen by 0.1 pH units, which represents approximately a 30% increase in acidity" (NOAA Pacific Marine Environmental Laboratory (PMEL), www.pmel.noaa.gov). This is attributed to the rise of CO2 levels in our atmosphere. Moreover, NOAA-PMEL reviews that by 2100 surface water could be 150% more acidic, the equivalent to a pH level lastly experienced by the oceans about 20 million years ago. Inevitably, coastal barriers experience some natural degradation caused by the force of the oceans waters crashing into the geological formations. But, how are the rates of degradation being affected by the decades of industrial pollution, which have accelerated atmospheric changes and increased the oceans acidity is not fully understood.

Carbonate eolianite forms distinctive coastal landforms on many mid-latitude continents and islands (Brooke, 2001, Figure 1). Physical and chemical changes known as *sediment diagenes* (Burdige, 2006) produced these calcium carbonate ($CaCO_3$) rich land forms. The fraction of CaCO3 dramatically affects the alkalinity and dissolved inorganic carbon (DIC) of seawater, and is thus important for understanding the processes that control the partial pressure of carbon dioxide in the atmosphere (Emerson and Hedges 2003).

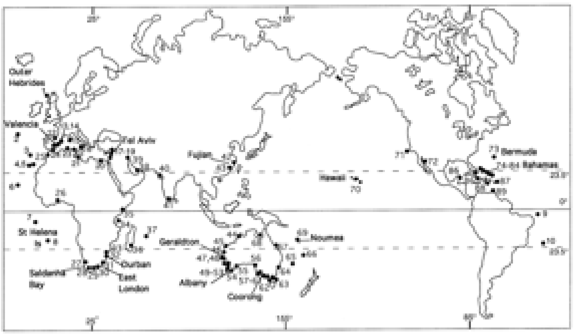

Figure 1. Global distribution of carbonate eolianite (from Brooke 2001).

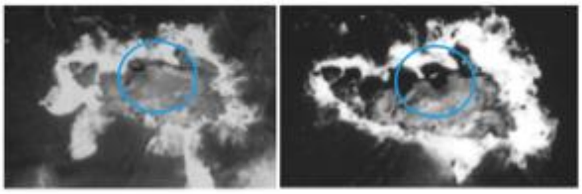

Figure 2. Aerial photographs (scale 1:1000) of Peñon Amador, Camuy, Puerto Rico for 1930 (left) and 1951 (right). The blue circles indicate regions of major impact.

Historical photographs of Puerto Rico's northern coast reveal substantial changes in the eolianite formations well before the effects of greenhouse gases absorbed by seawater were of concern. An example can be seen in Figure 2, where a good portion of the Eolianite was broken off between 1930 and 1951.

The particular scenario points towards a combined effect of chemical and physical stressors on the integrity of the eolianite, and potentially other coastal barriers such as coral and oyster reefs, and manmade barriers. We seek to investigate this phenomenon through a preliminary experimental study that combines both, an exaggerated drop in pH levels and fluid turbulence, in order to determine the potential degradation levels on the rock.

2. Methods

a. Sample collection

On August 6 2016, samples of eolianite rock were obtained from the northern coast of PR, specifically at "Poza las Golondrinas" in the municipality of Isabela (coordinates 18.514674, -67.059638, Figure 3). Samples consisted of broken pieces already available at the site (free from a matrix) and one cut from a permanent formation.

Figure 3. Eolianite formation where sampled were collected.

b. Pre-Treatment (controls)

In order to establish the controls, different physical properties were characterized prior to the physicochemical treatment. The samples were cut into 1-in slabs to allow for observation of the profile composition of the rock. Samples where produced for each cross-section of the rock: top, interior and bottom (Figure 4). The final product has the dimensions and shape of a *domino* piece. This is how we will refer to them for the remainder of the paper. In order to evaluate the mineralogy and carbonate binding very thin slices were also produced (Figure 5). One thin slice and two *dominos* were produced for each cross-section of the rock.

Figure 4. Eolianite cross-sections cut into *dominos*.

Figure 5. Thin slice preparation

i. Point Load

In order to assess the strength of the rock samples, the *dominos* were subjected to the Point Load Test using a *Geo Technical Systems Australia PTY. LTD Model 6500*. The ASTM D5731 was used as the testing procedure (ASTM 1985). The strength of the sample was assessed based on the force necessary for breaking. Samples from the top of the rock seem to be the strongest, while samples from the interior were the weakest (Figure 6). The strength of the samples after treatment is yet to be assessed.

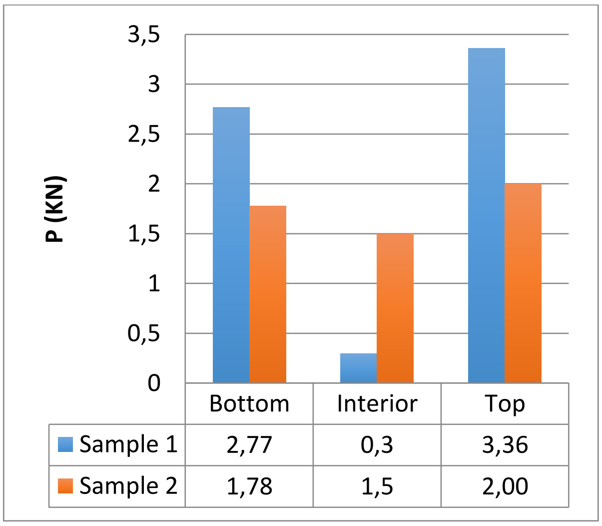

Figure 6. Strength of the dominos before treatment based on the Point Load Test.

c. Treatment

The rock sample was exposed to low pH seawater and fluid turbulence for a period of 70 days. To do this, a fish tank was filled with seawater and adapted to hold the rock sample flushed with a horizontal surface. A gas line containing a mixture of CO_2 and air (50%) was installed in order to provide continuous CO2 input into the water at an approximate flow rate of 47 ml/min. The tank was covered with a lid to prevent gas from escaping (Figure 7). Turbulence was provided by a fish tank pump (RMS horizontal velocities of O[20cm], Figure 8), and characterized using a Nortek Vectrino Profiler (Figure 8-top). The available turbulence level was characterized with the Reynolds stress (Figure 8-bottom).

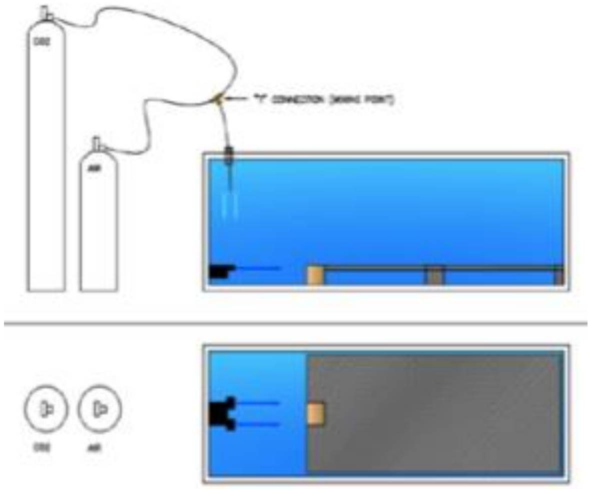

Figure 7. Experimental setup.

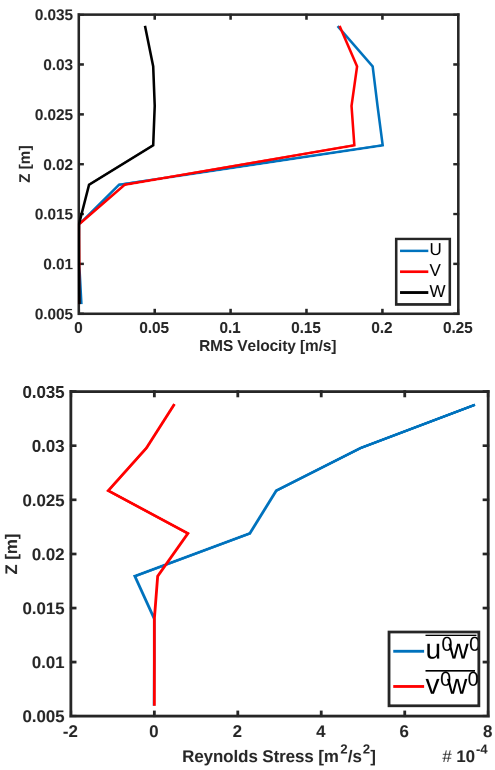

Figure 8. RMS velocities achieved by the pump (top) and corresponding Reynolds stresses (bottom).

3. Preliminary Results

After the treatment phase, surface changes were noticeable. The sample was weighted to determine potential mass and porosity changes. Additionally, photographs were taken before and after treatment to qualitatively assess changes in the sample morphology. The mass of the rock was reduced by an average of 2% while the porosity was increased by 11% (Table 1). The edges of the rock where considerably modified, in comparison to the lateral surfaces of the rock (Table 2).

Table 1. Mass Change

Mass Results			
	Wet mass (g)	Dry mass (g)	% Porosity
Before Treatment	1329.8	1231.6	7.4
After Treatment	1308.7	1201.2	8.2
Δ	21.1	30.4	
% Change	1.6	2.5	

The rock mass was reduced by an average of 25.8g while the porosity was slightly increased from 7.4% to 8.2%. The edges of the rock where considerably modified, in comparison to the lateral surfaces of the rock.

Table 2. Morphological study- Visual Comparison

4. Conclusions and Future Work

Preliminary quantitative and qualitative evidence suggests that indeed there is degradation of the eolianite rock in response to the combination of acidic water and fluid turbulence. While there are still post-treatment tests to be carried out (i.e. point load, carbonate binding, etc.), this experiment has provided sufficient data and experience to allow for the development of a more sophisticated experimental setup, including a variety of controls and different pH and turbulence levels. Our new setup, inspired on the Ocean Acidification Research Center | CFOS - College of Fisheries and Ocean Sciences, University of

Alaska Fairbanks” is currently being designed. Additional future work includes evaluating the time dependence of degradation rates to the above-mentioned chemical and physical stressors. These results may help determine erosion rates of eolianite coastal barriers and extrapolations into the future, where physical and chemical stressors may become even more prominent. This supports current and future efforts to develop: hazard mitigation plans, ecological impacts models and climate change resilience plans for coastal zones.

5. Acknowledgment

This work is primarily supported by the staff and faculty of CAOSE and CARICOOS. We also appreciate the extensive help of the following professors from the UPRM: Prof. Alessandra Morales, Prof. Wilson Ramirez, Prof. Ruben Diaz from the Departments of Civil Engineering and Survey, Geology and Mechanical Engineering, respectively. Graduate students Erick Garcia and Luis Rodriguez from Department of Marine Science and undergraduate student Jorge Algarin from the Mechanical Engineering Department. In addition, we would like to recognize the sustained support of the following laboratory technicians: Perla Torres (Environmental Engineering Lab.), Jaime Ramirez (Soil Engineering Lab.), Elvis Ramos (Structural Engineering Lab.), Jennifer Toledo (Geological Science Lab.) and Luis Rodriguez (Fluid Dynamics Lab.).

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